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STRAIN GAGE PROGRAM FOR AC-6
HYDROGEN TANK SKIN,
RESULTS AND DISCUSSION

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ABSTRACT

This report discusses the work of the Stress Measurements Group which was required to install a successful flight strain measurement system on the NASA/Convair Centaur (AC-6) liquid hydrogen fuel tank skin. This work included planning, evaluation, installation, and checkout of the strain gage system. Baldwin universally compensated FNB-50-12E strain gages were selected to provide the following:

1. Operate at -423°F.
2. Measure individual strains which are easily convertible to skin stress.
3. Have a minimum zero shift during temperature excursions of from 70°F to -423°F.
4. Be reliable during the several months period between the installation date and the flight date.

Results of laboratory and full scale testing are presented. The flight date is discussed in the body of the report and in Appendix G.

REFERENCES

1. A. Kaufman, Performance of Electrical-Resistance Strain Gages at Cryogenic Temperatures, NASA Technical Note D-1663.

2. C. T. Wu, Lateral Sensitivity, Baldwin-Lima-Hamilton Corp.

3. Procedure for Soldering of Electrical Connections (High Reliability), NASA Huntsville MSFC-PROC-158B.

4. Sales Order No. 333-1-148 T.D. 126, Strain Gage Instrumentation of AC-6 Flight Vehicle.

5. A New Strain Gage for Use at Cryogenic Temperatures, Carl R. Harris, John E. Davis by Baldwin-Lima-Hamilton Corp.

6. Strain Gage Results for Centaur 4D Structural Tests, Axial Load and Bending Moment Test (Phases I and II) and Pitch Axis Bending Moment. Report No. 55B3309-3.

7. Atlas/Centaur Flight Evaluation Report, Vehicle AC-6, Report No. GDC-BNZ-65-037.

8. Analysis of AC-6 Flight Strain Gage Data, Convair Report No. AS-D-991.

1.0 INTRODUCTION:

The NASA/Convair Centaur upperstage liquid hydrogen fueled vehicle is being developed to place a Surveyor payload on the moon. This unmanned vehicle is a successor to the highly reliable Air Force/Convair Atlas from the standpoint of structural design. It is a pressure stabilized thin-skinned cylinder of type 301 corrosion resistant steel. The structural designers worked to certain assumed loading conditions based on past Atlas flights and to Centaur vehicle performance specifications. The NASA personnel at Lewis Research Center, Cleveland, Ohio, as program managers, directed that certain steps be taken to compare actual flight loads to flight load assumptions. A measurement of stress in the primary structure was of particular interest to the customer (NASA) and Convair designers in considering the present safety factors and possible future weight reductions.

Maximum acceleration loads were expected just prior to Atlas booster engine cutoff. Maximum shear loads were expected in the upper atmosphere at high velocity. Axial air loads were expected to increase as velocity increased. Manuevers would result in bending moments being applied to the vehicle structure. Although accelerometers would be of primary interest in flight instrumentation, the most direct way to determine structural stresses caused by these loads would be to measure strain at various points of interst.

A. OBJECTIVE

The objective was to measure strain in the primary structure throughout powered flight to determine flight stresses.

B. PROJECT APPROACH

The measurement of strains on the Centaur fuel tank was a project which involved the persistence, cooperation and hard work of many people in many departments at Convair and at the NASA Lewis Research Center. The acknowledgements mentions a few. In addition to the technical information, some mention of the coordination role of the Stress Measurements Group is included throughout the report as organization information. The complexity of strain gage measurements has been recognized and the Test Laboratory Strain Gage Engineers have been given the continuous responsibility for successful strain measurements from planning to data evaluation on numerous programs. This scheme was welcomed by the many groups responsible for the steps from design to reporting on AC-6. This organization approach worked well, as did the strain gages.

2.0 **SUMMARY OF RESULTS:**

A. Fourteen strain measurements were successfully accomplished on the liquid hydrogen tank skin of AC-6 during flight.

B. Success was directly attributable to the effort, attention to detail and cooperation of many groups in planning, evaluation testing, installation checkout and data follow-through.

C. Temperature compensation was excellent during the temperature excursion from 70°F down to -420°F.

D. Data check points showed excellent correlation during flight.

E. Insulation panel influence on strain readings during pressure changes made the flight moment load calculations inaccurate.

F. Stress calculations for the local areas under the strain gages are accurate although these stresses cannot be extropolated to determine moment loads.

3.0 **TEST SPECIMENS:**

Test specimens are discussed in more detail in the reference documents, in the body of the report and in the appendices. They can be summarized as follows.

a. AC-6 Flight Liquid Hydrogen Fuel Tank.

b. Point Loma Structural Test Vehicle EID 55-7545.

c. Evaluation Test Strain Gages.

1. Budd Co. C9-121-R2B gages for material property tests.

2. Baldwin FNB-50-12E gages. Lot No. 64/7N (same as AC-6 tank strain gages).

d. Material Property Coupons from 0.014 thick 301 XFH heat No. 71583, coil 1741-AZ (same as AC-6 fuel tank).

4.0 **PROCEDURES:**

Procedures are discussed in their chronological order to include planning through data reduction as accomplished by the Stress Measurements Group and others.

4.0 PROCEDURES: (Cont'd)

A. PLANNING

Since the basic structure was a single, nearly uniform cylinder, the most obvious place for strain gages was on the vehicle skin itself. Although insulation panels surround the tank, there would be about 0.10 in. clearance between the panels and the skin for purge gas to pass. This was enough for strain gages and lead wires. There were many possible combinations of gage locations, orientations and special bridge arrangements to measure the desired quantities. However, the final analysis showed that the most useful end result would be minimum and maximum principle skin stresses. If it were correctly assumed that these stresses would be in the direction of the flight path and at right angles to the flight path, two individually wired gages at each location would be sufficient.

Eighteen telemetry channels were made available for strain measurement on the tank skins. Locations were selected as shown in Figure 1. The next step was the selection of materials to measure these strains. The fuel tank makes up nearly the entire length of the fuel and oxidizer composite tank structure. Strain gages on this tank surface were expected to see a temperature of about -420°F. Since the airborne signal conditioning would have to be balanced and calibrated before tanking (for safety reasons), the gage had to have a minimum zero shift in going from 70°F down to -420°F. In other words, the telemetry information band width would have to allow for all effects of this zero shift plus the flight changes.

The gage had to be as rugged as possible to survive handling of the vehicle for several months between strain gage installation and the launch date. The strain gage had to have predictable characteristics at cold temperatures (gage factor, linearity, etc.). Planning for the program was summarized in the memo reproduced as Appendix A.

1. Strain Gage Selection

The most suitable strain gage was the Baldwin-Lima-Hamilton FNB-50-12E universally compensated, Bakelite encapsulated, nichrome/platinum gage. This gage had the lowest potential zero shift and proved to be rugged and predictable during past experience in low temperature applications. The details of the gage are shown in Figure 2. The selection was made and transmitted to Centaur Instrumentation Design in the memo reproduced as Appendix B.

4.0 **PROCEDURES:** (Cont'd)

A. **PLANNING** (Cont'd)

2. Cement Selection

Experience on several large programs had shown Budd Co. GA-5 cement to be satisfactory at temperatures down to -423°F. NASA-Lewis tests had also shown this cement to be excellent (Reference 1). Waterproofing requirements for the gages and solder connections were minimized by the presence of dry purge gas under the insulation panels. Therefore, a thin coat of GA-5 cement was used over the exposed leads and gages.

3. Additional Materials and Methods

Budd Co. No. 3 soldering tabs were selected to be bonded near the gages for lead wire terminals. Teflon-coated wire was necessary at the very low temperatures. The Teflon insulation was etched to permit good bonding of the moisture proofing.

Surface preparation for the gages included abrasive blasting (velvetizing) the skin, cleaning with detergent and rinsing all surfaces before cement application.

4. Theory of Strain Gage Circuit

The Baldwin FNB-50-12E strain gage is unique because it provides the possibility of zero bridge output at two or more temperatures and a low magnitude of zero shift between these temperatures. This is made possible by the presence of a platinum element in the gage which can be used to cancel the temperature zero shift of the nichrome strain sensing element. Baldwin literature explains the theory quite well but does not fill in some of the details. After making the decision to use this gage, it was discovered, upon closer examination of the problem, that the lead wire was going to have a large effect on the zero position. Long lengths of lead wire would be cooled to cryogenic temperatures. From early temperature data, it was evident that the bridge would not be an equal arm bridge and the lead wire temperature changes would be significant. The solution was as follows:

Conditions for initial room temperature balance are shown in Figure 2. Strain sensor resistance (R_G), temperature sensor element resistance (R_T), and lead wire resistance (R_L), are shown in Figure 3. R_1, R_2 and R_B are contained in the signal conditioning package. The R_L values, R_G and R_T will change

4.0 **PROCEDURES:** (Cont'd)

A. **PLANNING** (Cont'd)

4. Theory of Strain Gage Circuit (Cont'd)

with temperature. R_G (nichrome) will decrease with a decrease in temperature to -423°F. R_T (platinum) will decrease slightly more than R_G in going down to -423°F. If R_B is the proper value, the following will be true for no change in zero balance (neglecting leadwire).

$$\frac{R_G\,70°}{R_T\,70° + R_B} = \frac{R_G{-423°}}{R^T{-423°} + R_B} = \frac{R_G 70° + \Delta R_G}{R_T 70° + \Delta R_T + R_B} \qquad (1)$$

EXAMPLE: $\frac{120\,\Omega}{3.5\,\Omega + 140} = \frac{119\,\Omega}{2.3\,\Omega + 140}$

Nichrome decrease = $-1\,\Omega = \Delta R_G$

Platinum decrease = $-1.2\,\Omega = \Delta R_T$

ΔR_G = Change in resistance of the nichrome strain sensor.

ΔR_T = Change in resistance of the platinum compensator.

The leads are changing temperature, so R_L will change and the following will be true for no change in zero balance.

$$\frac{R_G 70° + R_L 70°}{R_T 70° + R_L 70° + R_B} = \frac{R_G{-423°} + R_L{-423°}}{R_T{-423°} + R_L{-423°} + R_B} = \frac{(R_G 70° + \Delta R_G) + (R_L 70° + \Delta R_L)}{(R_T 70° + \Delta R_T) + (R_L 70° + \Delta R_L) + R_B} \qquad (2)$$

ΔR_L = Change in resistance in the lead wire (assumed to be the same for both arms).

For a given set of changes from 70°F to -423°F, there is only one R_B value which will satisfy the equation. Equal changes in adjacent arms of the bridge do not cancel each other except where the total resistance of the arms are equal so lead wire changes do not cancel. R_B does not change since it is in the signal conditioning box. The correct value can be determined by solving equation (2) for R_B. The result is

4.0 PROCEDURES: (Cont'd)

A. PLANNING (Cont'd)

4. Theory of Strain Gage Circuit (Cont'd)

$$R_B = \frac{(\Delta R_T + \Delta R_L)(R_G + R_L)}{\Delta R_G + \Delta R_L} - (R_T + R_L)$$

Where

R_B = Ballast resistance needed for identical zero balance at 70°F and 423°F.

The values required to solve equation (3) were determined experimentally as described in Section B4 below.

To summarize, it can be said that lead wire temperature effects were considered significant and a method different than that normally used was devised to reduce zero shift to a minimum.

B. EVALUATION TESTING

Evaluation testing included the laboratory tests which are performed to (1) determine suitable materials and methods, (2) prove installation reliability and (3) determine needed values for use in data evaluation or circuit design.

The evaluation work included the following tasks.

1. Sample installations.
2. Gage factor determination at three temperatures.
3. Transverse sensitivity determination.
4. Circuit constant determinations.
5. Material properties (3 temperatures, 2 directions).
6. Quality control coupon tests.
7. Zero shift vs. temperature testing.

1. Sample Installations

As mentioned above, the strain gages and materials were selected by the Stress Measurements Group on the basis of previous experience. This information was supplied to the Centaur Instrumentation Design Group. A formal installation drawing was prepared. Before engineering release, it was reviewed by the Stress Measurements Group in detail. The suggested changes were incorporated and the drawing was released as Convair Dwg. No. 55-12505 (Figures 4 and 5).

4.0 PROCEDURES: (Cont'd)

B. EVALUATION TESTING (Cont'd)

1. Sample Installations (Cont'd)

Prototype installations were then made on samples of the type 301 CRES skin material in exactly the manner called out on the production drawing. These specimens were then subjected to thermal shock (-423°F) and strain to verify the materials and methods. Results were satisfactory and no changes were required.

2. Gage Factor Determination

Gage factor was expected to change with temperature extremes. The extent of this change was determined by the use of a dual bending beam fixture and a cryostat similar to that reported by Kaufman (Reference 1) and shown in Figure 6. The 70°F gage factor supplied by Baldwin was considered to be sufficiently accurate and changes from this were determined by comparison of strain values measured at 70°F, -320°F, and -423°F on the same gage experiencing identical strains at the three temperatures. Results are listed in Table I and plotted in Figure 7 as an average of four samples.

3. Transverse Sensitivity Determination

Transverse sensitivity (strain output due to strain at right angles to the grid) was known to be appreciable on the FNB-50-12E gage. The presence of transverse output was obviously going to effect stress calculations on a biaxial stress field such as is found on a cylinderical pressure vessel. Three gages were mounted on the transverse sensitivity fixture (described in Reference 2) which produces a uniaxial strain field. One gage was mounted with the sensitive axis parallel to the strain developed. Two gages were mounted at right angles to the first (i.e., parallel to the zero strain direction). The ratio of these outputs was equal to the transverse sensitivity. The ratio was found to be -2.78% and -2.92% for the gages tested. Earlier tests using five gages showed the ratio to be -2.90%. The manufacturer states -2.9% for this ratio.

4. Circuit Constant Determinations

Determinations of the quantities in equation (3) were accomplished as follows. R_G and R_T for each installed gage were measured with the vehicle at a known pressure and temperature. R_L was calculated from length measurements of the wire installed on the

4.0 **PROCEDURES:** (Cont'd)

B. EVALUATION TESTING (Cont'd)

4. Circuit Constant Determinations (Cont'd)

vehicle. The changes in lead wire resistance (ΔR_L) were calculated from test data which showed ohms/ohm change for a given temperature drop (see Figure 8). During tanked conditions, some of the leads were considered to be at -423°F and some at -350°F.

Resistance changes of the gages, ΔR_G, were calculated from test data of similar gages (same production lot) which gave a percent change in resistance while the gage temperature went from 70°F to -423°F. The same method was used for determining ΔR_T. All resistances were measured with a digital ohmmeter and the data considered to be accurate to ±.02 ohms.

Measurements and calculations for the vehicle gages are shown in Table II.

Gage element resistances were measured and calculated as shown in Figure 2, to standardize nomenclature and to obtain the most accurate values.

Notice that R_G and R_T cannot be determined by simple subtraction of two readings since the current path during resistance measurement (R_g) of the sum of R_G and R_T shortcuts from the platinum to the lower nichrome section. This method of measurement is important since the "corner" of the Wheatstone bridge will lie about at the dot on the sketch and the temperature effects in the portion called R_X is not pertinent to this analysis.

5. Material Properties

Severely rolled stainless steel has one set of material properties in the direction of rolling and another in the direction transverse to rolling. In calculating stress from strain in a biaxial field, it was deemed necessary to determine the modulus of elasticity and Poisson's Ratio in both directions. Temperature effects were also required. Right-angle rosette strain gages were mounted back to baqk on tensile coupons (9 in. long x 1.5 in. wide with a 0.5 in. wide test section). Four coupons with the rolling direction parallel to the long centerline and four with the rolling direction at right angles to the long centerline were instrumented and tested at 70°F, -320°F and -423°F. The coupons were immersed in liquid nitrogen and liquid hydrogen

4.0 **PROCEDURES:** (Cont'd)

B. **EVALUATION TESTING** (Cont'd)

5. Material Properties (Cont'd)

for the two low temperatures using a vacuum jacketed cryostat fitted into a Baldwin tensile test machine. Results are shown in the table below. They were also transmitted in memo form before flight. The memo is reproduced in Appendix C.

CRES TYPE 301 MATERIAL PROPERTIES AT THREE TEMPERATURES

Temperature	Grain Direction	Modulus of Elasticity	Poisson's Ratio
70°F	Longitudinal	26.4×10^6	-.272
	Transverse	30.0×10^6	-.312
-320°F	Longitudinal	30.1×10^6	-.280
	Transverse	33.9×10^6	-.313
-423°F	Longitudinal	30.2×10^6	-.298
	Transverse	33.3×10^6	-.326

6. Quality Control Specimens

The technical direction for the installation and checkout of the gages was the responsibility of the Stress Measurements Engineer assigned to the project. Tests of sample installations were made to determine quality of bonding. During the installation of gages on the vehicle, several tensile test coupons were taped down next to the vehicle gage locations. As the work progressed in the factory area, test gages were installed on the coupons with nearly identical materials, conditions, techniques, cure cycle, etc. After the vehicle work was complete, the coupons (containing a very close approximation of the tank strain gage installation) were pulled at -423°F to 5000 microstrain to establish that the materials and workmanship were acceptable.

7. Zero Shift vs. Temperature Testing

Temperature measurements were made during flight at the two station levels on the fuel tank where the strain gages were located. From these measurements, it was possible to correct the strain data for zero shift. The following is a summary of

4.0 PROCEDURES (Cont'd)

B. EVALUATION TESTING (Cont'd)

7. Zero Shift vs. Temperature Testing (Cont'd)

the testing which was done to establish the zero shift vs. temperature correction curve.

First, an appropriate ballast resistance R_B was determined by immersing the four mounted test strain gages in hydrogen. A hit and miss dunking test in hydrogen was anticipated to be expensive and time consuming, even with a calculated R_B to start with. A short cut method was devised whereby several R_B values for each gage were selected at room temperature and balanced with known changes in the bridge completion resistances. The four specimens were tested in LH_2 and the R_B values were again set in steps as at room temperature. Strain readings (zero shift) at each R_B (and corresponding balance resistance reading) were recorded. A plot such as Figure 9 was made. The recorded zero shift at -423°F (vertical scale) is plotted vs. R_B setting in ohms (horizontal scale). The several points for each gage form a nearly straight line for small ranges of R_B. Where this line crosses zero on the zero shift axis, the correct R_B can be read on the horizontal scale.

Temperature chamber tests of the mounted strain gages were then performed using these correct R_B values in the external bridge circuit. The specimen temperature was lowered from 75°F to -314°F in one chamber and from -340°F down to -423°F in another chamber. Additional data was obtained at -320°F (in liquid nitrogen). The bridge output was measured at increments of temperature change and plotted later. A composite of the four curves is shown in Figure 10. Further information is given in Appendix D.

C. STRAIN GAGE INSTALLATION

One important aspect of the organizational approach taken on this and all other factory strain gage installations, was the close technical direction of the technicians by the Stress Measurements Engineer. Virtually all strain gage work on flight vehicles at Convair is done by the same technicians. They install gages for research, test, and production. Approved strain gage installation procedures are written by Stress Measurements and specified on the drawings (these are not Manufacturing Specifications). Although the Inspection Department approves all work progressively, the final technical

4.0 PROCEDURES: (Cont'd)

C. STRAIN GAGE INSTALLATION (Cont'd)

authority lies with the Stress Measurements Engineer. He also prepares an Installation Log which records all installation data and final readings of individual strain gages. The installation was recorded as S-1498 in the Stress Measurements files. The procedure for installing the gages for this project is reproduced as Appendix E and is briefly summarized below. The locations are shown in Figure 1. A typical mounted strain gage is shown in Figure 11. Strain gages used on the vehicle were Baldwin-Lima-Hamilton Lot No. 164-7N, type FNB-50-12E. Part of the installation procedure was the measurement of resistance as discussed in Section B4 (gage element resistances, lead wire resistances). The resistance to ground checks were specified throughout the installation. Soldering quality was inspected and continuity checks were made for lead wire and connector pin identification. NASA soldering procedure (Reference 3) MSFC-PROC-158B was followed for all strain gage circuits.

Strain Gage Installation Procedure (See Appendix E)

1. Locate gage positions from production drawing (check).*
2. Velvetize (S. S. White air abrasive unit) area under gages and soldering tabs to light grey color (check).
3. Detergent wash and rinse with distilled water.
4. Place gage and tabs in proper relation on clean layout template and pick up with Scotch Tape and locate on tank (check).
5. Mix and apply GA-5 cement and apply with glass rod to gage area and gage.
6. Press gage in place.
7. Apply Teflon sheet, sponge rubber pad and aluminum plate with tape to hold firmly in place.
8. Room temperature cure 2 hours.
9. Raise temperature slowly and cure at 180°F for 4 hours.
10. Remove pads and Scotch Tape (check).

*(check) Stress Measurements Engineer checks and initials log.

4.0 PROCEDURES: (Cont'd)

C. STRAIN GAGE INSTALLATION (Cont'd)

Strain Gage Installation Procedure (See Appendix E) (Cont'd)

11. Wire to tabs (check).

12. Route lead wires and solder in place. Spotweld lead wire hold-downs (check).

13. Coat wires and solder joints with GA-5 cement and repeat cure Steps 8 and 9 (check).

D. CHECKOUT PROCEDURE

System checkout was begun after the strain gage installation was complete and following delivery of the signal conditioning package by NASA Lewis. Factory checkout was limited to a Strain vs. Pressure test and periodic triple measurements of each gage circuit as mentioned above. The pressure test assured us that each gage circuit was capable of indicating the proper amount of strain in the correct direction. The resistance checks were made to detect any changes which would affect our circuit calculations or show damage to the gage circuits.

Prelaunch checkout included (1) another Pressure vs. Strain test without insulation panels bolted to the tank, (2) a Pressure vs. Strain test with panels bolted on, and the tank at 70°F and (3) another pressure test with panels on and with the tank filled with liquid hydrogen. These checks assured us that the circuits were all good, the panel effect was known and that the circuit was in fact compensated such that the data traces all remained on scale at useable levels.

Just prior to each pressure test, the series resistance calibration was made in each circuit by inserting a sandwich plug between the gages and the signal conditioning. The simulator (calibration) box was then plugged into this plug to reroute the circuits into a resistance and switching network for calibration. A shorting plug could be used in place of the simulator box for zero added resistance in each circuit. When calibration was complete, the sandwich plug, shorting plug and simulator box were removed to the black house and the gages were connected into the telemetry signal conditioner.

4.0 PROCEDURES: (Cont'd)

D. CHECKOUT PROCEDURE (Cont'd)

The signal conditioning was designed and manufactured by NASA Lewis under the direction of Frank Maruna. Questions regarding this equipment may be directed to him in Cleveland. The telemetry hardware was standard 0-5 volt, band edge to band edge, GD/Convair design.

E. DATA REDUCTION

Flight data was received at Cape Kennedy and recorded on magnetic tape. The tape was flown back to San Diego and processed by computer into digital values (2 1/2 samples/sec.). Computer outputs were time, strain, stress, moments, temperatures and axial load. The computer program incorporated corrections to the raw data for material properties changes, gage factor change, zero shift and transverse sensitivity. Output was tabulated and also plotted against time from liftoff. The diagram below shows the flow of the data during handling. Strain plots are shown in Reference 7, and calculated stresses and loads are presented in Reference 8 as tables and plots (vs. time).

FLOW SHEET FOR DATA HANDLING

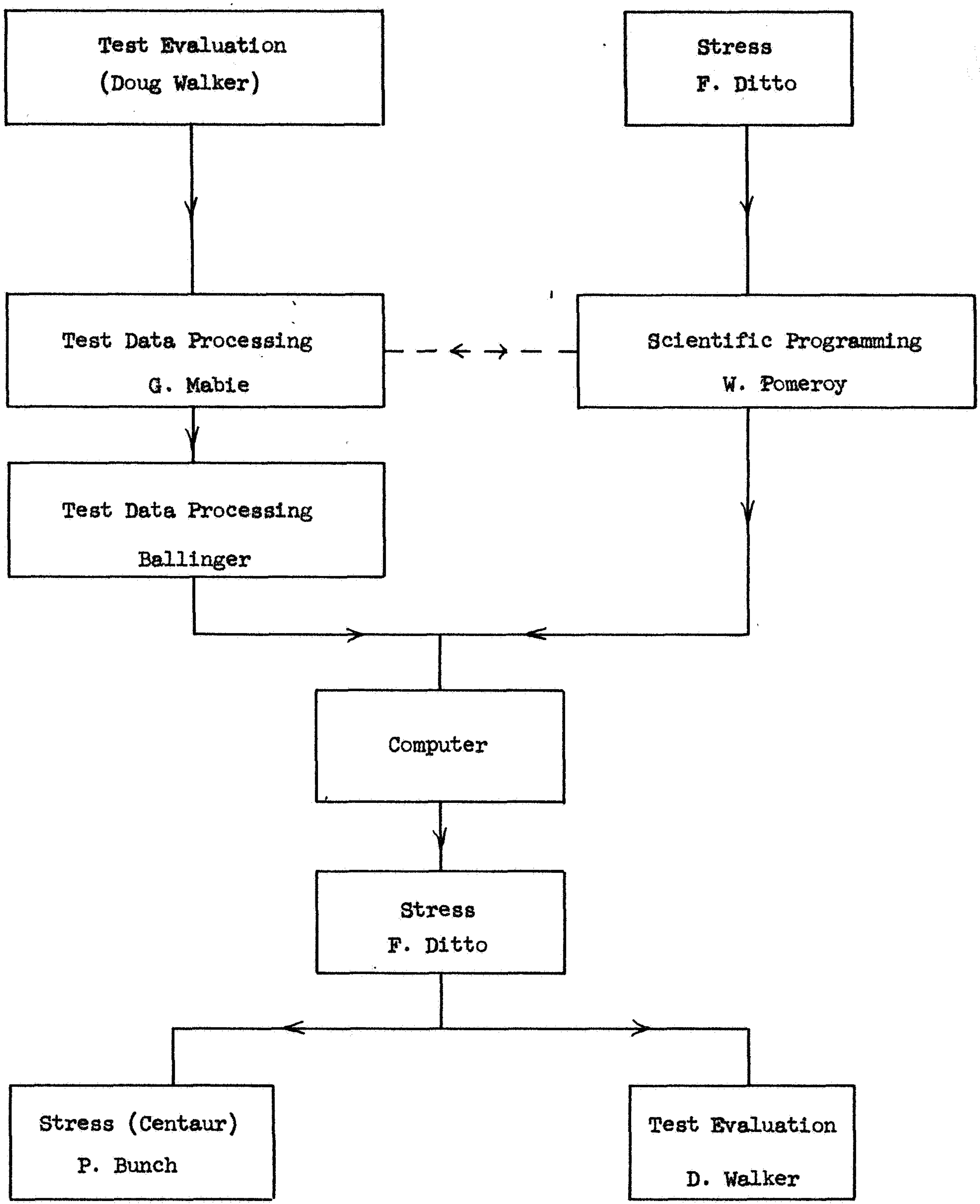


FIGURE 1

5.0 TEST RESULTS:

A. FULL SCALE TEST RESULTS

Full scale test tanks are produced and subjected to extensive ground testing in preparation for flights. As part of one such program, 72 Baldwin FNB-50-12E strain gages were installed on a full scale test tank. The results of the testing program on this tank are of interest here. Complete results are recorded and discussed in Reference 6.

1. Test Tank Reliability

The strain gage installation on the test tank was started in October 1964 while the tank was in a factory dock. Thirty-one of the strain gages were installed inside the tank. The tank was then moved 10 miles to the test stand. Twelve tankings with liquid nitrogen were accomplished during testing, and as of 1 June 1965, two gages of the initial 72 have failed to function properly. No rework has been done since original installation.

2. Full Scale Test Tank Checkout

A few days prior to the structural test date, a validation test was performed to check the various systems in operation. This test included the strain gage system. The vehicle tanks were filled with liquid nitrogen and pressures were varied.

The least complicated gage results are shown in the table. They show the correlation of theoretical strain to measured strains due to tanking (head pressure) and pressure change. These are the lowest hoop direction gages and they were chosen because they show the largest influence from head pressure. The hoop strain is calculated using the biaxial equation for a two-gage rosette. Pressure due to tanking is calculated from the theoretical density of liquid nitrogen and the height from station 225 to station 397. Measured strain due to tanking is the difference between the average of five hoop gages at station 225 and the average of five hoop gages at station 397 (below). Measured strain due to a tank pressure increase from 4.1 psig to 11.1 psig was taken directly from the data tape.

5.0 **TEST RESULTS:** (Cont'd)

A. **FULL SCALE TEST RESULTS:** (Cont'd)

2. Full Scale Test Tank Checkout (Cont'd)

VALIDATION TEST RESULTS SUMMARY - STATION 397

Theoretical Strain for 1 psig Tank Press.	Measured Strain - Reduced Test Data	
	Due to Pressure Increase	Due to LN_2 Tanking Head Pressure
122$\mu\epsilon$	122$\mu\epsilon$	125$\mu\epsilon$

3. Full Scale Test Tank Load Test

The full scale structural test program included numerous load conditions. The strain results from a simple axial acceleration load will illustrate the quality of data obtained from the strain gage installation. The measured strain was 8% less than theoretical strain. However, the load carried by the insulation panels would reduce the tank load and the resulting measuring strain values.

Calculated Strain	Measured Strain - Reduced Data in $\mu\epsilon$							
	1	2	3	4	5	6	7	8
-746$\mu\epsilon$	640	630	570	660	770	835	725	660
	695$\mu\epsilon$ Avg. Measured							

4. Full Scale Test Tank Pressurization Results

Flight results are discussed below and in Appendix F. One problem encountered with the flight vehicle data was the unpredictable moments resulting from tank pressurization. The Point Loma data is examined here as background information for discussion of flight results.

5.0 TEST RESULTS: (Cont'd)

A. FULL SCALE TEST RESULTS (Cont'd)

4. Full Scale Test Tank Pressurization Results (Cont'd)

Table III shows strain changes resulting from pressurization of the test tank from standby pressures to test pressures before test loads were applied. Ideally, no moment should result from pressurization. Therefore, strain values for all strain gages in a given orientation should increase equally for a given pressure increase (since skin thickness is assumed to be 0.014 in. at all locations). For one psi increase in pressure the strain changes should be as follows:

Longitudinal strain increase	28 microinches/in./psi
Hoop strain increase	121 microinches/in./psi

The transverse sensitivity factor of -2.9 percent will further reduce these values to

Longitudinal strain reading	24 $\mu\epsilon$ /psi
Hoop strain reading	120 $\mu\epsilon$ /psi

Looking at Table III it can be noted that the strain increases are less than theoretical. This has been shown in Reference 6 to be caused by insulation panel restraint by comparing "panels on" and "panels off" pressure test strain data. Reference 6 also shows that measured axial stress is nearly equal to calculated theoretical values in random sample comparisons. Note from Table III that the response of a given strain gage location changes from one test to another. Both inside and outside strain gage readings are shown. The difference between these readings is due to bending. In most cases the bending is not severe. However, this could add to the inaccuracy of load calculations in which strains on one side of the tank skin are used. Figure 12 shows this variation between inside and outside gages for test No. 7 (Sta. 412 Ultimate Design). In most cases the inside gage increases more than the outside gage except at locations at 225° (longitudinal) and 315° (hoop).

From Figures 13, 14, and 15 the change in stress can be seen. These stress calculations are derived from average strain values (inside and outside gages). Figure 13 shows a fairly uniform increase in hoop stress due to pressure increase from test to test (Tests 1, 2, 3, 7). However Figure 14 shows considerable difference in response at locations around the tank for longitudinal stress. These stresses again are based on average strain values.

5.0 TEST RESULTS: (Cont'd)

A. FULL SCALE TEST RESULTS (Cont'd)

4. Full Scale Test Tank Pressurization Results (Cont'd)

The above factors are enough to show why it is difficult, if not impossible, to calculate moments from tank strain gages. In addition, no information exists which would show the effect of increasing and decreasing pressure several times. With insulation panel friction and panel load paths complicating the strain picture, it is obvious that no accurate correction factor can be devised for flight use.

B. FLIGHT VEHICLE RESULTS

Flight vehicle tank strain results can be summarized in two statements. (1) Sophisticated strain gages were successfully employed to measure tank surface strains. (2) Moment load analysis was complicated by the presence of the insulation panels in contact with the thin tank skin. The discussion of these two statements can be extended into a career for the strain gage Engineer. However, the result would more than likely be a recommendation that a similar installation would result in a similar data analysis enigma. In view of the program cost, some discussion must be recorded to justify the opinion stated above and in Appendix G.

The strain gages were unquestionably reliable from the standpoints of operation and accuracy. At no time was there any rework required on the strain gage bonding or circuit up to the terminal plugs. Temperature compensation was achieved as shown in the checkout summary table in Appendix F, columns 10 and 11. Since severe thermal stresses would be expected from a temperature drop of 500°F, the difference indicated between columns 10 and 11 can be attributed to tank head pressure and thermal stresses due to tanking. Accuracy of measurement is indicated in Appendix F, Page 2. The close agreement between theoretical and measured stresses is gratifying indeed. However, the values shown are for averages of all gages around the tank at station 241 and do not reveal the basic problem of moment measurement.

The moment loads during flight would be reflected in equal and opposite strain changes on opposite sides of the moment axis. Any "other influences" which result in unequal strain changes in the moment load calculation also look like moments. "Other influences" were present on AC-6. These were (1) insulation panel restraint, (2) local effects of the insulation panel contact points, (3) discontinuities in the tank structure, and (4) unmeasureable

5.0 **TEST RESULTS:** (Cont'd)

B. **FLIGHT VEHICLE RESULTS** (Cont'd)

effects of pressure between the insulation panels and the fuel tank skin. The presence of these influences (which apparently changed from time to time) precluded the correction of the data for moment load determination.

C. **FLIGHT DATA DISCUSSION**

The following is a typed copy of the comments contained in the flight report (Ref. 7) pertaining to the fuel tank strain gages.

VEHICLE AXIAL LOADS AND BENDING MOMENTS

Centaur LH_2 tank strain gage data acquired from the AC-6 flight has been converted to stress using the IBM 7094 DCS digital computer program number 3833. In addition to computing stress, the program computed bending moments at Station 241 and 397. Bending moment calculations are based on a relationship between stress differences around the tank circumference. A brief review of the computer results indicates that the measured stress was in good agreement with theoretical values. Bending moments computed from the measured stresses exhibited reasonable distribution. However, the values were excessive. Based on this review, bending moment data obtained, cannot be used without modification.

The probable cause for the excessive bending moments were local stress discontinuities due to insulation panels and other sources. The presence of discontinuities resulted in a variation in stress around the tank circumference, giving the same indication as an applied bending moment.

Considerable evaluation will be required to account for these secondary effects before the bending moment can be used. In lieu of the uncorrected plots of stresses and bending moments obtained from the computer program, the data from the individual strain gage measurements are presented in Figures 2.10-8 through 2.10-15.

5.0 **TEST RESULTS:** (Cont'd)

C. **FLIGHT DATA DISCUSSION** (Cont'd)

Figures 16 through 21 are reproductions of flight data contained in the flight report. Although these are only strain traces, some comments can be made. The flight events are conveniently noted at the bottom of each page. Figure 22 is a reproduction of some strain gage temperatures which were also contained in the flight report.

The most reliable checkpoint is at BECO. The increase in strain due to the drop in acceleration at BECO is almost identical for all six longitudinal gages at station 241 and all four longitudinal gages at station 397. This shows the strain response to axial load to be uniform. In spite of the influence of the insulation panels during the changes in pressure before this time, the strain gages can be assumed to be indicating strain accurately. Therefore, flight stresses as calculated from the strain gages in general are accurate for the local areas under the strain gages.

At panel jettison, the effects on the various longitudinal gages varies. This supports the assumption that panel influences are present. Hoop strain response also varies slightly.

The abrupt change in strain in all longitudinal gage traces is uniform at SECO. The longitudinal gages were also sensitive enough to show "steps" at nose fairing jettison, main engine start, and main engine cutoff. Acceleration increase is accurately shown on all longitudinal gages from 400 sec. to MECO with very little, if any, drift. Measurements CA925S, CA927S, and CA929S all have a quick negative shift at about 675 seconds right after correctly indicating a zero acceleration point. After several seconds CA931S also drops the same amount and at 715 sec. CA933S makes the same drop. No explanation is offered for this drop to a new stable level.

Confusion is noted early in the flight from 0 time to 60 seconds since the longitudinal gages show various responses to the large tank pressure change. Measurement CA943S seems to indicate a drop from an artificial zero strain point before engine start to a more reasonable value after engine start shock and the associated vibration.

Reasonably good response to increasing acceleration from 100 sec. to BECO is shown by all longitudinal gages.

5.0 **TEST RESULTS:** (Cont'd)

C. **FLIGHT DATA DISCUSSION** (Cont'd)

The hoop strains show a very uniform drop with the pressure drop at 70 seconds, however, their response to mach 1 conditions at 60 seconds is dependent on their station level. The strain increase due to pressure increase from time 0 to 50 seconds is also nearly uniform for all four hoop gages. This would indicate that the longitudinal gages were adversely influenced to the greatest extent by the insulation panels. Unfortunately they were the source of the bending moment information.

Temperature effects (strain gage zero shift) are not great up to 175 seconds while the panels are on the vehicle. Immediately after panel jettison the temperature increased until it went out of range. Maximum temperature correction (160 microinches/inch) was expected to be made at -350°F. A correction of +2.3 micro-inches/in. per °F should be used in the range going from -420°F to -350°F.

6.0 **RECOMMENDATIONS:**

A. The Baldwin FNB-50-12E strain gage should be considered for all cryogenic stress measurement tasks where individual strain gage temperature compensation is required and sufficient space is available for its installation.

B. Complex strain gage tasks such as this should be funded in the same way with respect to the strain gage engineers task. It should include sufficient budget for data and results evaluation immediately after program completion as well as continuous responsibility throughout planning, evaluation, installation, and testing.

C. No suggestions for improved load measurement accuracy can be made, using the same installation locations.

7.0 ACKNOWLEDGEMENTS:

Great impetus to fly strain gages on Centaur was supplied by NASA Lewis (T. Lull). A large part of the strain gage work was done by the Stress Measurement Engineers, L. Foglesong, D. Neff and E. Winslow. The signal conditioning for AC-6 was designed and built by NASA Lewis (F. Maruna) and the General Dynamics Convair design drawings for AC-6 strain gage installation were under the direction of E. Davies. Computer coordination was handled by F. Dittoe, Convair Stress Group. These few men were in turn assisted by many others in making the program a success.

DEFLECTION VS. MEASURED STRAIN
NASA BEAM FIXTURE. GAGE TYPE FNB-50-12E
LOT NO. 64-7N GAGE FACTOR 2.26 ± 2%.

DEFLECTION INCHES	AMBIENT TEMP.						-320°F						-423°F					
	STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.			STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.			STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.		
	RUN 1	RUN 2	AVG.	RUN 1	RUN 2	AVG.	RUN 3	RUN 4	AVG.	RUN 3	RUN 4	AVG.	RUN 5	RUN 6	AVG.	RUN 5	RUN 6	AVG.
0.0000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0.1247	510	509	510	-515	-500	-508	552	550	551	-563	-550	-557	560	550	555	-560	-550	-555
0.2438	978	988	983	-1000	-990	-995	1072	1050	1061	-1088	-1070	-1079	1060	1015	1038	-1075	-1065	-1070
0.3490	1395	1406	1401	-1420	-1408	-1414	1510	1490	1500	-1520	-1508	-1514	1510	1495	1503	-1510	-1500	-1505
0.4984	1908	1965	1937	-1915	-1968	-1947	2132	2100	2116	-2110	-2115	-2113	2145	2120	2133	-2125	-2120	-2123
0.3484	1278	1330	1304	-1260	-1320	-1290	1465	1425	1445	-1428	-1430	-1429	1460	1440	1450	-1450	-1450	-1450
0.2422	860	910	885	-832	-888	-860	1020	972	996	-970	-970	-970	1010	990	1000	-1000	-1000	-1000
0.1215	432	435	434	-377	-418	-398	490	458	474	-450	-450	-450	485	480	483	-470	-475	-473
0.0006	-78	-40	-59	112	60	86	-40	-70	-55	90	80	+85	-70	-70	-70	90	70	80
-0.1226	-575	-530	-553	610	550	580	-550	-595	-573	610	610	610	-580	-605	-593	600	610	605
-0.2415	-1018	-992	-1010	1060	1020	1040	-1075	-1100	-1088	1138	1125	1132	-1100	-1120	-1110	1120	1120	1120
-0.3441	-1400	-1380	-1390	1451	1410	1432	-1510	-1540	-1525	1575	1570	1573	-1520	-1560	-1540	1540	1560	1550
-0.4902	-1870	-1862	-1866	1980	1911	1996	-2120	-2140	-2130	2180	2170	2175	-2150	-2175	-2163	2190	2190	2190
-0.3421	-1235	-1225	-1230	1340	1270	1305	-1470	-1480	-1475	1520	1500	1510	-1480	-1500	-1490	1500	1505	1503
-0.2376	-800	-800	-800	920	840	880	-1013	-1030	-1022	1065	1050	1058	-1030	-1060	-1045	1040	1055	1048
-0.1172	-348	-330	-339	460	375	418	-490	-508	-499	540	520	530	-510	-540	-525	530	540	535
-0.0000	+132	+150	+141	-40	-120	-80	30	10	20	10	000	5	+20	000	+10	0	5	3

NOTE:
1. SR-4 GAGE FACTOR SETTING. 2.00 ALL ABOVE READINGS RECORDED WITH THIS G.F.
2. BOTH GAGES MOUNTED IN LONGITUDINAL DIRECTION ON BEAM.

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE

FORM 73 (REV 6-61)

5504053

TABLE II

AC-6 TANK STRAIN GAGES BALLAST RESISTOR CALCULATION

MEAS. NO.	R_G^* OHMS	R_T^* OHMS	R_L OHMS	L_3 FT.	L_4 FT.	K_G OHMS/OHM	K_T OHMS/OHM	ΔR_G^* OHMS	ΔR_T^* OHMS	K_{L3} OHMS/FT.	K_{L4} OHMS/FT	ΔR_{L3} OHMS	ΔR_{L4} OHMS	ΔR_{LT} OHMS	$\Delta R_T+\Delta R_{LT}$ OHMS	$R_G^* + R_L$ OHMS	$\Delta R_G+\Delta R_{LT}$ OHMS	$R_T^* + R_L$ OHMS	$R_G+R_T^*+R_L$ OHMS	R_B OHMS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
								2 x 7	5 x 8			5 x 11	6 x 12	13 + 14	10 + 15	2 + 4	9 + 15	3 + 4	$\frac{16 \times 17}{18}$	20 - 19
CA925S	117.75	3.87	0.23	0	3.4	0.0221	0.879	2.602	3.402	[illegible]	0.022	0	0.0748	0.0748	3.477	117.98	2.677	4.10	153.24	149.14
CA927S	117.53	3.77	0.16	0	2.0	0.0221	0.879	2.597	3.314	[illegible]	0.022	0	0.0440	0.0440	3.358	117.69	2.641	3.93	149.64	145.71
CA928S	117.49	3.80	0.16	0	2.0	0.0221	0.879	2.598	3.340	0.020	0.022	0	0.0440	0.0440	3.384	117.65	2.640	3.96	150.81	146.85
CA929S	118.07	3.82	0.18	0	3.4	0.0221	0.879	2.609	3.358	[illegible]	0.022	0	0.0748	0.0748	3.433	118.25	2.684	4.00	151.25	147.25
CA931S	117.78	3.82	0.26	0	5.9	0.0221	0.879	2.605	3.358	0.020	0.022	0	0.1298	0.1298	3.488	118.04	2.733	4.08	150.65	146.57
CA933S	117.57	3.73	0.12	0	14.8	0.0221	0.879	2.598	3.279	[illegible]	0.022	0	0.3256	0.3256	3.605	117.99	2.924	4.15	145.47	141.32
CA934S	117.67	3.82	0.45	0	14.8	0.0221	0.879	2.600	3.358	[illegible]	0.022	0	0.3256	0.3256	3.684	118.12	2.926	4.27	148.72	144.45
CA935S	119.78	3.81	0.46	0	14.8	0.0221	0.879	2.647	3.349	0.020	0.022	0	0.3256	0.3256	3.675	120.24	2.973	4.27	148.65	144.36
CA937S	118.48	3.86	0.58	16	4.9	0.0221	0.879	2.618	3.393	0.020	0.022	0.3200	.1078	0.4278	3.821	119.06	3.046	4.44	149.35	144.91
CA939S	117.96	3.83	0.58	16	4.0	0.0221	0.879	2.607	3.366	0.020	0.022	0.3200	0.0880	0.4080	3.774	118.54	3.015	4.41	148.38	143.97
CA940S	117.76	3.82	0.66	16	4.0	0.0221	0.879	2.602	3.358	0.020	0.022	0.3200	0.0880	0.4080	3.766	118.32	3.010	4.38	148.84	143.66
CA941S	118.37	3.83	0.79	16	13.8	0.0221	0.879	2.616	3.366	0.020	0.022	0.3200	0.3036	0.6236	3.990	119.16	3.240	4.62	146.74	142.12
CA942S	118.44	3.82	0.79	16	13.8	0.0221	0.879	2.617	3.358	0.020	0.022	0.3200	0.3036	0.6236	3.982	119.23	3.241	4.61	146.49	141.88
CA943S	117.04	3.85	0.82	16	13.6	0.0221	0.879	2.586	3.384	0.020	0.022	0.3200	0.2992	0.6192	4.003	117.86	3.205	4.67	147.20	142.53

R_G^* STRAIN ELEMENT RES. (CALC. FROM MEAS.)

R_T^* PLATINUM SENSOR RES. (CALC. FROM MEAS.)

R_L ONE HARNESS WIRE RES. (MEASURED AND CALC.)

L_3 LENGTH OF WIRE EXPOSED TO M350°F

L4 LENGTH OF WIRE EXPOSED TO M423°F

K_G RES. CHANGE CONST. FOR R_G^* FROM 72°F TO M423°F (EXPERIMENTAL)

K_T RES. CHANGE CONST. FOR R_T^* FROM 72°F TO M423°F (EXPERIMENTAL)

$\Delta R_G^* = R_G^* \cdot K_G$

$\Delta R_T^* = R_T^* \cdot K_T$

K_{L3} RES. CHANGE CONST. FOR L_3 (EXPERIMENTAL)

K_{L4} RES. CHANGE CONST. FOR L_4 (EXPERIMENTAL)

$\Delta R_{L3} = L_3 \cdot K_{L3}$ RES. CHANGE IN LEAD WIRE SUBJECT TO 72°F TO M320°F CHANGE

$\Delta R_{L4} = L_4 \cdot K_{L4}$ RES. CHANGE IN LEAD WIRE SUBJECT TO 72°F TO M423°F CHANGE

$\Delta R_{LT} = \Delta R_{L3} + \Delta R_{L4}$ TOTAL RES. CHANGE IN A SINGLE LEAD DUE TO TEMP. CHANGE

$$R_B = \frac{(\Delta R_T + \Delta R_{LT})(R_G^* + R_L)}{\Delta R_G + \Delta R_{LT}} - (R_T^* + R_L)$$ BALLAST RESISTOR

TABLE III

INDICATED STRAIN CHANGE DUE TO 1 PSI TANK PRESSURE CHANGE

Point Loma Tests on EID 55-7545 Test Tank

		Test No. 1 $\Delta P = 7.12$ psi		Test No. 6 $\Delta P = 14.21$ psi		Test No. 9 $\Delta P = 14.08$ psi	
Sta. 241		L	H	L	H	L	H
48°	Outside	9.6	110.1	15.0	108.9	13.2	115.2
	Inside	26.4	117.6	19.6	121.7	20.0	120.4
	Average	18.0	113.9	17.3	115.3	16.4	117.8
73°	Outside	6.6	115.1	14.6	94.9	10.2	116.1
	Inside	22.5	126.4	13.6	117.8	12.6	118.3
	Average	14.6	120.8	14.1	106.4	11.4	117.2
90°	Outside	5.6	113.2	12.4	117.8	9.3	118.4
	Inside	17.7	133.3	14.3	122.6	11.0	124.0
	Average	11.7	123.3	13.4	120.2	10.2	121.2
107°	Outside	6.8	113.4	10.4	113.1	11.5	117.4
	Inside	23.1	131.0	20.0	116.4	15.9	114.1
	Average	15.0	122.2	15.2	114.8	13.7	115.8
135°	Outside	15.3	106.4	23.4	112.2	18.1	113.9
	Inside	25.9	127.6	21.9	119.2	20.0	117.3
	Average	20.6	117.0	22.7	115.7	19.1	115.6
225°	Outside	12.4	111.9	22.0	113.5	16.3	113.9
	Inside	21.5	131.6	20.1	122.1	18.1	121.7
	Average	17.0	121.8	21.1	117.8	17.2	117.8
270°	Outside	13.3	64.5	20.5	115.7	15.1	118.0
	Inside	19.3	132.0	20.0	118.9	16.3	121.2
	Average	16.3	-	20.3	117.2	15.7	119.6
315°	Outside	14.7	116.5	18.0	112.6	17.9	121.9
	Inside	14.2	125.2	18.1	120.6	15.5	74.3
	Average	14.5	120.9	18.1	116.6	16.7	-
Sta. 397							
45°	Outside	7.9	123.9	6.6	123.0	7.6	108.7
125°	Outside	8.3	120.6	20.6	117.0	12.6	166.0
225°	Outside	8.9	122.0	8.2	113.5	12.1	119.2
270°	Outside	20.6	117.0	17.7	118.4	17.4	112.1
305°	Outside	8.2	120.9	4.5	121.4	3.9	113.9

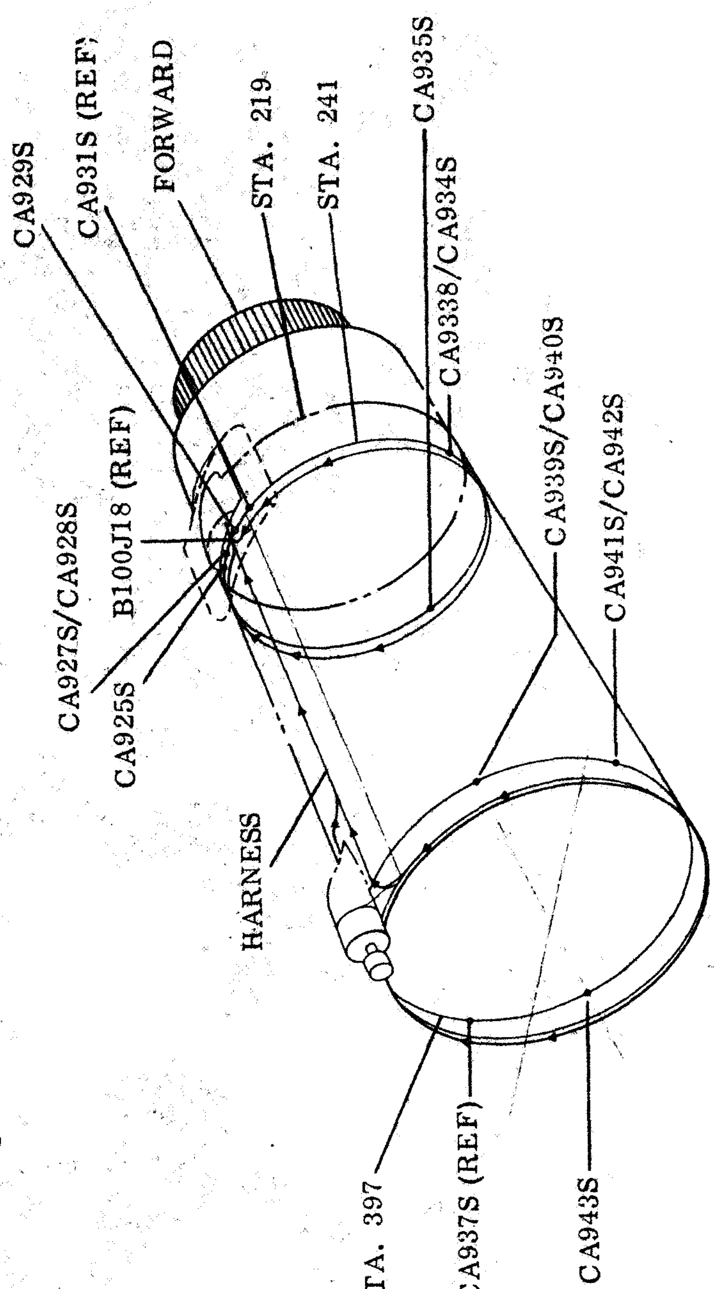
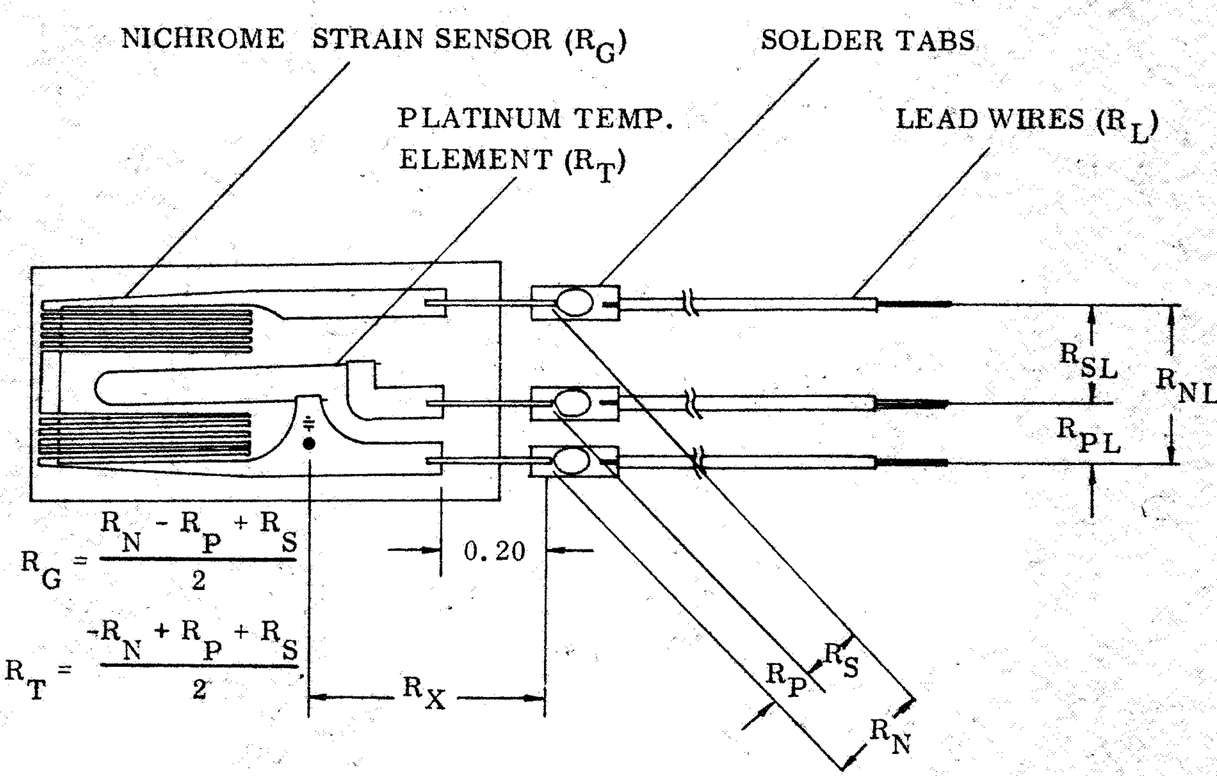


Fig 1 STRAIN GAGE & LEADWIRE LOCATIONS ON AC-6

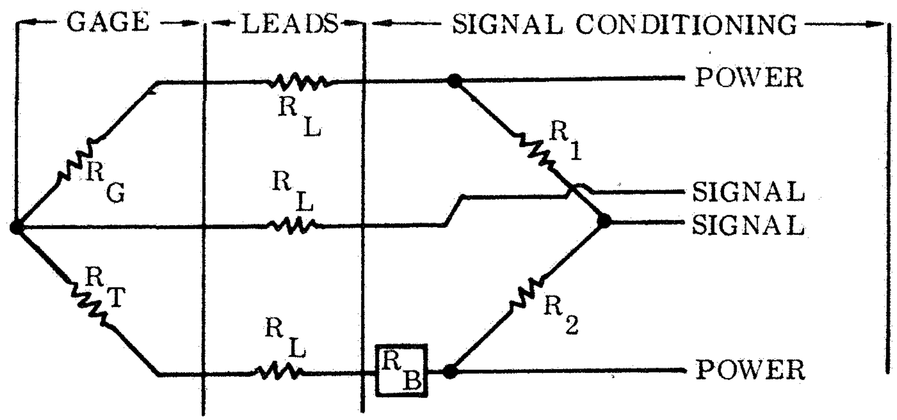
Fig 2 RESISTANCE OF B-L-H STRAIN GAGE FNB-50-12E



$$R_G = \frac{R_N - R_P + R_S}{2}$$

$$R_T = \frac{-R_N + R_P + R_S}{2}$$

Fig 3 FNB-50-12E STRAIN GAGE CIRCUIT



R_G = Resistance of strain sensor (120 Ω) R_L = Lead resistance

R_T = Resistance of temperature sensor (3.5 Ω) R_B = Ballast resistance

$R_1 = R_G + R_L$ $R_2 = R_T + R_L + R_B$

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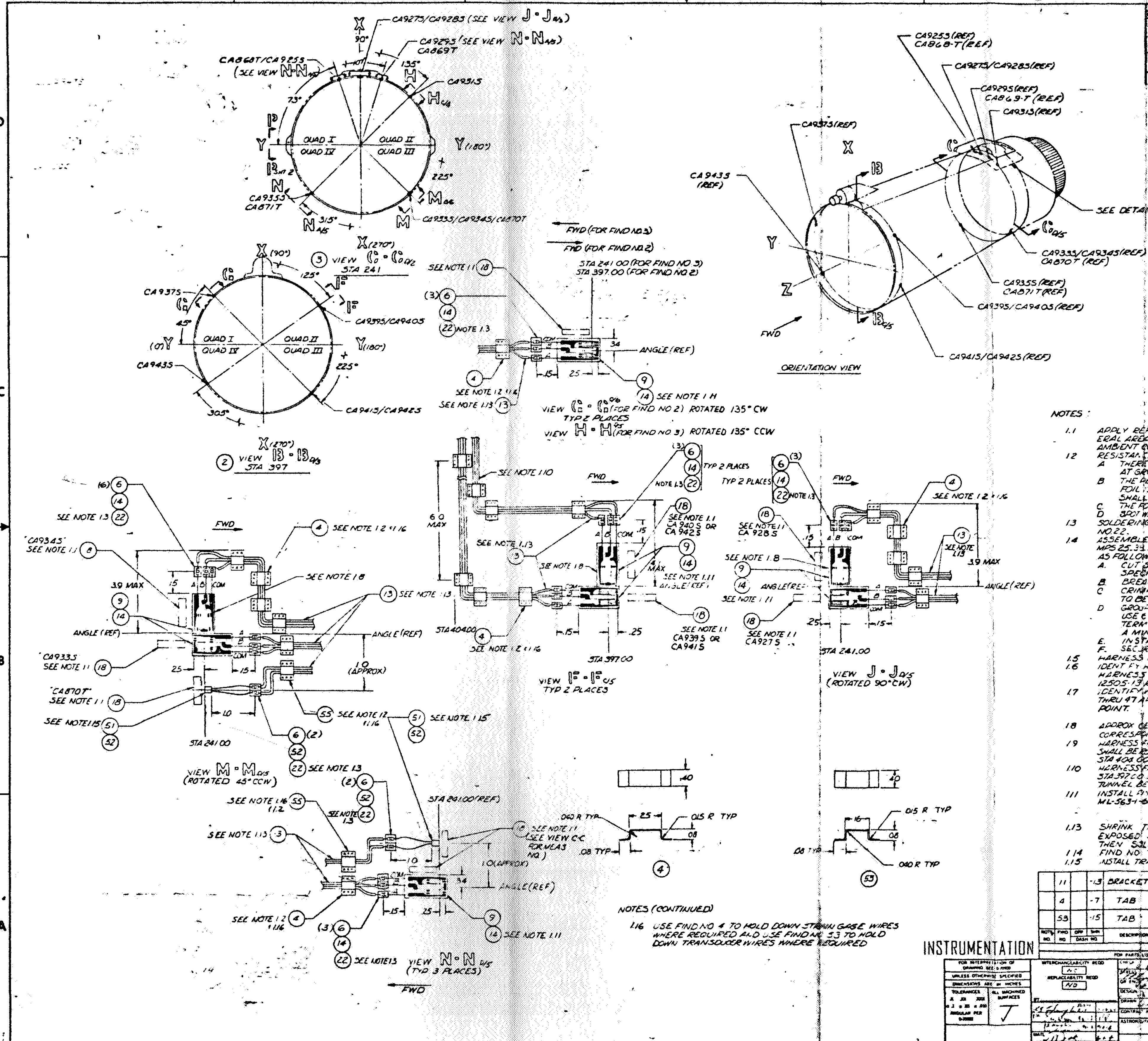
Sym	Zone	Description	Date	Approved
A		SEE ECN CIC 35925-963-4-2 D HOSAKA 2-10-5		
B		SEE ECN CIC 36134-963-4-1 D HOSAKA 2-275		



NOTES :

1.1 APPLY REF DESIGNATORS APPROX .19 HIGH IN GENERAL AREA INDICATED WITH FIND NO 8 PER 0-79018 AMBIENT CURE.

1.2 RESISTANCE WELD PER MPS 43.04 EXCEPT AS FOLLOWS
- A THERE SHALL BE NO HOLES IN FOIL, NOR PITTING AT GROUND ELECTRODE.
- B THE PEEL STRENGTH OF EACH SPOT WHEN THE FOIL IS PULLED NORMAL TO THE BASE MATERIAL SHALL BE MINIMUM OF 1.0 POUND (TEST SPECIMEN)
- C THE FOIL USED SHALL BE 321 CRES .003±.0005 IN THK.
- D SPOT WELD AT 3 PLCS APPROX AS SHOWN ON F/O.

1.3 SOLDERING TO BE PER MSFC-PROC-158B USING FIND NO 22.

1.4 ASSEMBLE CRIMP-TYPE POKE-HOME CONNECTOR PER MPS 25.33.3 AND FORM SHIELD GRD AT CONNECTOR AS FOLLOWS :
- A. CUT SHIELDED WIRES 3 INCHES LONGER THAN SPECIFIED.
- B. BREAK OUT A 3 INCH SHIELD BRAID.
- C CRIMP WIRES TO CONNECTOR. SHIELD BREAK-OUT TO BE 1/2 INCH MAX FROM ENDBELL.
- D GROUP SHIELD BRAIDS FROM WIRES TO FIND NO 48 USE 6 SHIELD BRAIDS PER TERMINAL, MAX. ADD TERMINALS AS REQUIRED SHIELD BRAIDS TO BE A MINIMUM LENGTH
- E. INSTALL FIND NO 7 IN CONNECTOR
- F. SECURE TERMINALS TO BOTH SIDES OF ENBELL EARS

1.5 HARNESS TO BE FABRICATED PER C-79044

1.6 IDENTIFY HARNESSES AND CONNECTOR PER MPS 28.19 HARNESS 10 TO INCLUDE EASR REV LETTER, IE, 55-12505-13 REV O D SERIALIZED PER SP4-3.

1.7 IDENTIFY WIRES WITH PIN LETTER MARKERS FIND NO 24 THRU 47 APPROX 3 OR 4 INCHES FROM EACH TERMINATION POINT.

1.8 APPROX CENTER LINE OF STRAIN SENSING ELEMENT TO CORRESPOND WITH STATION LINE.

1.9 HARNESS FROM STRAIN GAGES INSTALLED ON SEAL PLATE SHALL BE ROUTED IN DIRECTION OF WIRING TUNNEL BETWEEN STA 404.00 AND STA 406.00

1.10 HARNESS FROM STRAIN GAGES INSTALLED ON TANK AT STA 397.00 SHALL BE ROUTED IN DIRECTION OF WIRING TUNNEL BETWEEN STA 402.00 AND STA 404.00

1.11 INSTALL FIND NO 9 PER LATEST REVISION OF PROCEDURE ML-563-1-64-43

1.13 SHRINK THERMOFIT SLEEVING FIND NO 49 OR 50 OVER EXPOSED SHIELD OF FIND NO 13 PER MPS 25.33 THEN SOLDER FIND NO. 13 TO FIND NO 6 TERMINAL.

1.14 FIND NO 7 TO BE SUPPLIED BY ENGINEERING

1.15 INSTALL TRANSDUCERS PER MPS 82.29 EXCEPT SOLDER PER NOTE 1.3.

NOTES (CONTINUED)

1.16 USE FIND NO 4 TO HOLD DOWN STRAIN GAGE WIRES WHERE REQUIRED AND USE FIND NO 53 TO HOLD DOWN TRANSDUCER WIRES WHERE REQUIRED

Note No.	Find No	Opp Dash No	Shn Dash No	Description	Stock Size	Material Specification	Initial Cond or Ht TR	Final	Zone
	11		-13	BRACKET	.063 × 5 × 14	2024 AL ALY CLAD / QQ-A-362	T3	T3	C/25
	4		-7	TAB	.003 × 6 × 4	321 CRES / QQ-S-766	A	A	
	53		-15	TAB	.003 × 5 × 4	321 CRES / QQ-S-766	A	A	

LIST OF MATERIALS

FOR PARTS LIST AND USAGE DATA SEE DOCUMENT SAME NUMBER PREFIXED PL

INSTRUMENTATION

FOR INTERPRETATION OF DRAWING SEE S-7000
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES .X ±.1 .XX ±.03 .XXX ±.010 ANGULAR PER 0-35000
ALL MACHINED SURFACES

INTERCHANGEABILITY REQD A/C
REPLACEABILITY REQD N/D

CONTRACT NO

ASTRONAUTICS APPROVAL

GENERAL DYNAMICS | ASTRONAUTICS
SAN DIEGO, CALIFORNIA

STRAIN GAGE INSTL-TANK

CODE IDENT NO. 05342 | SIZE E | DRAWING NO. 55-12505

SCALE NONE | SHEET 1 OF 2

103-15-0

CIC31021-963-4-1

FIGURE 4

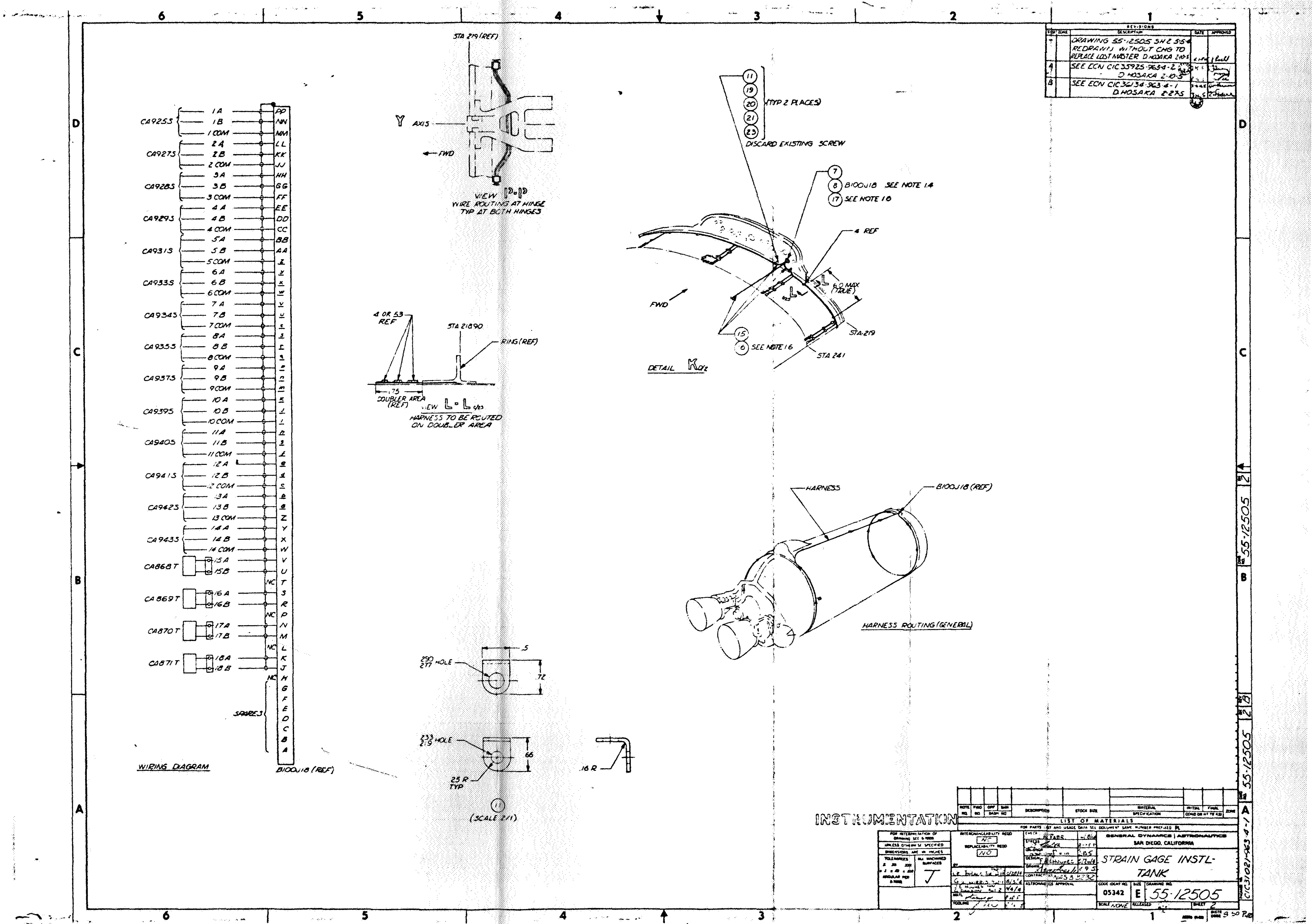

WIRING DIAGRAM
B100J18 (REF)
SPARES
VIEW P-P
WIRE ROUTING AT HINGE TYP AT BOTH HINGES
Y AXIS
FWD
STA 219 (REF)
STA 218.90
RING (REF)
4 OR 53 REF
DOUBLER AREA (REF)
VIEW L-L
HARNESS TO BE ROUTED ON DOUBLER AREA
(TYP 2 PLACES)
DISCARD EXISTING SCREW
B100J18 SEE NOTE 14
SEE NOTE 16
4 REF
STA 219
STA 241
DETAIL K
HARNESS
HARNESS ROUTING (GENERAL)
(SCALE 2/1)
INSTRUMENTATION
LIST OF MATERIALS
GENERAL DYNAMICS | ASTRONAUTICS
SAN DIEGO, CALIFORNIA
STRAIN GAGE INSTL-TANK
05342
E
55-12505

FIGURE 5

Fig 6 GAGE FACTOR FIXTURE & CRYOSTAT FOR USE WITH LIQUID HYDROGEN

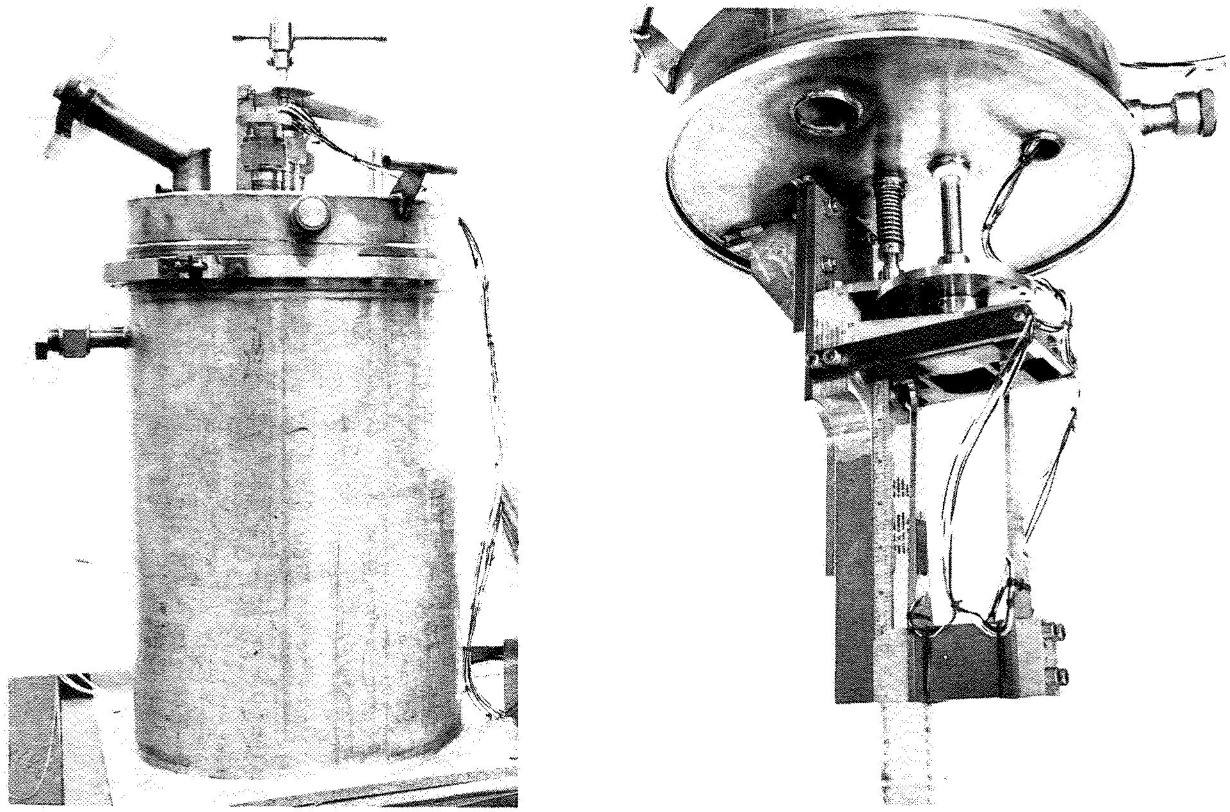


Fig 7 GAGE FACTOR CHANGE WITH TEMPERATURE

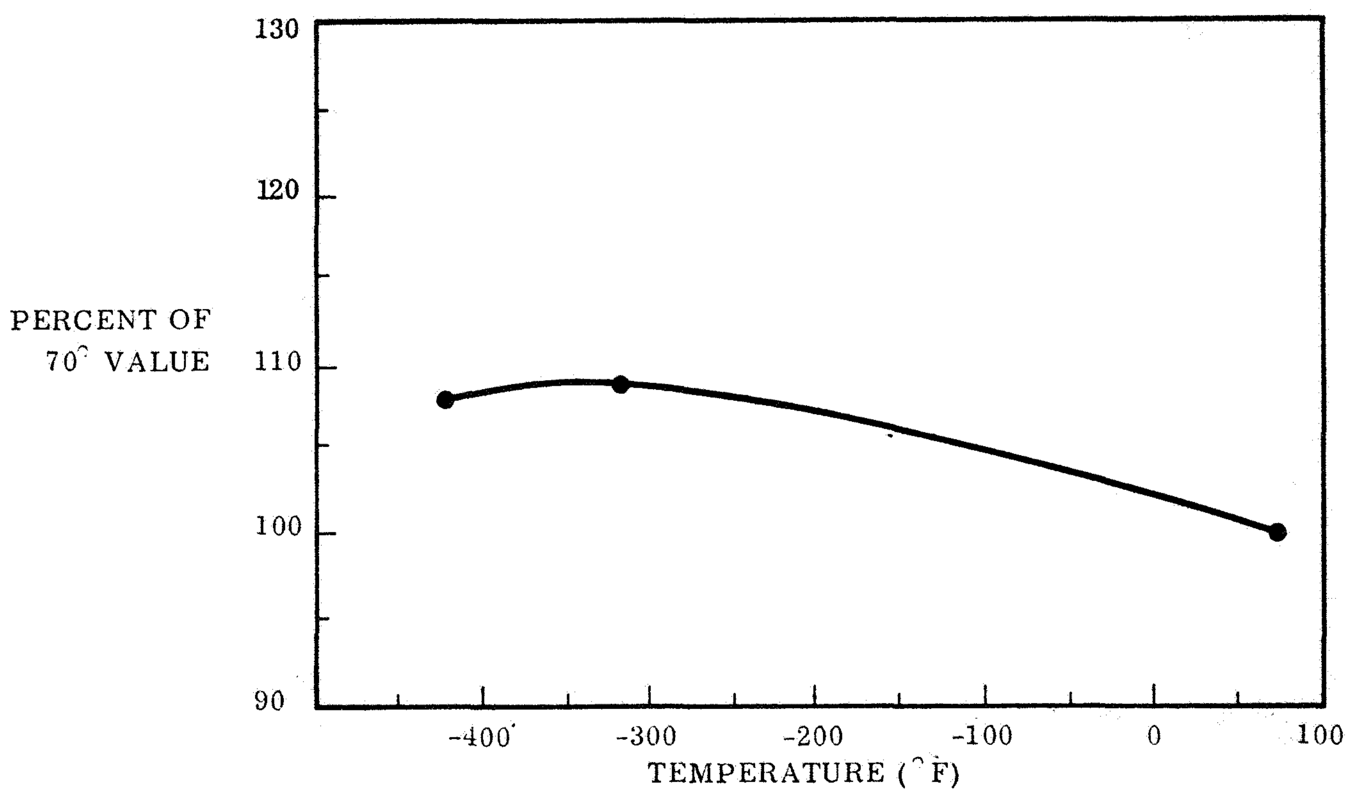


Fig 8 RESISTANCE CHANGE OF COPPER WIRE WITH TEMPERATURE

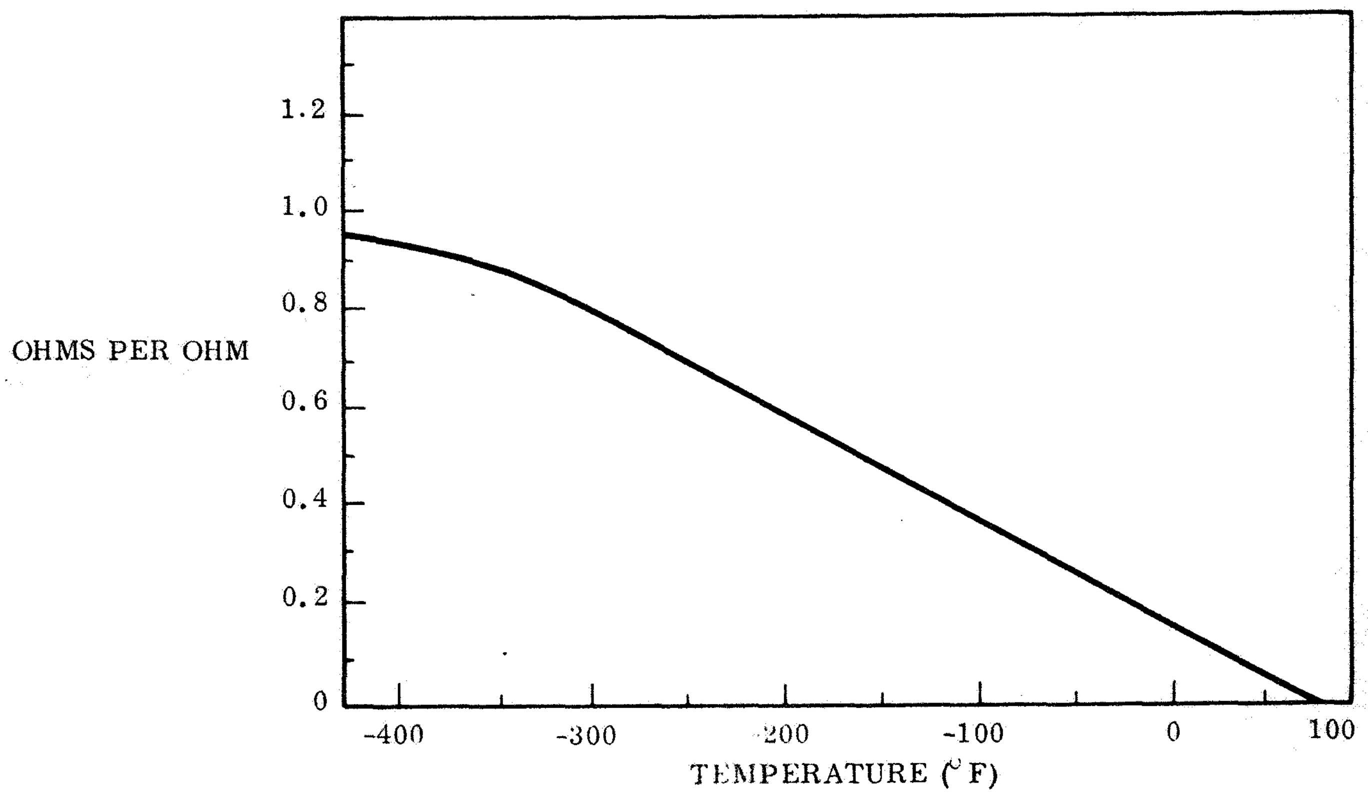


Fig 9 BALLAST RESISTANCE DETERMINATION CURVES

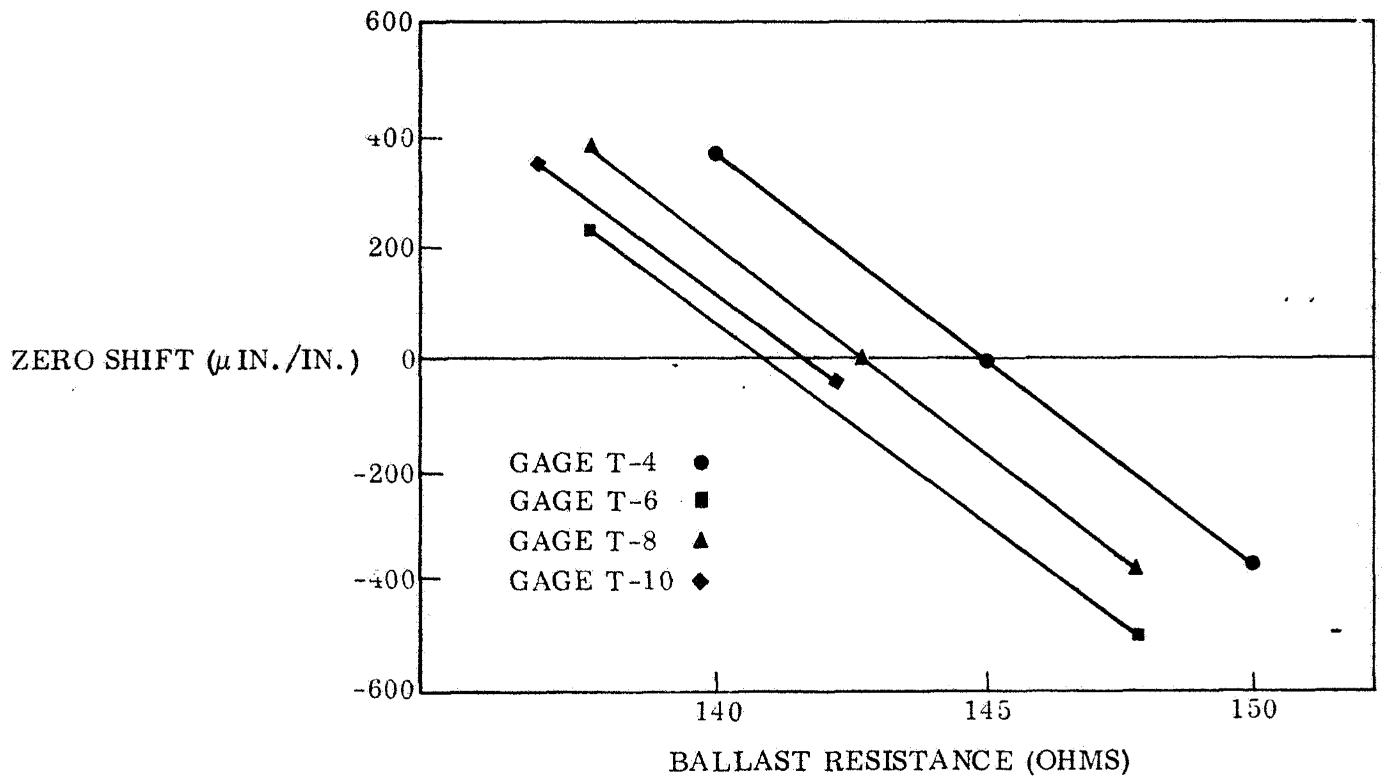
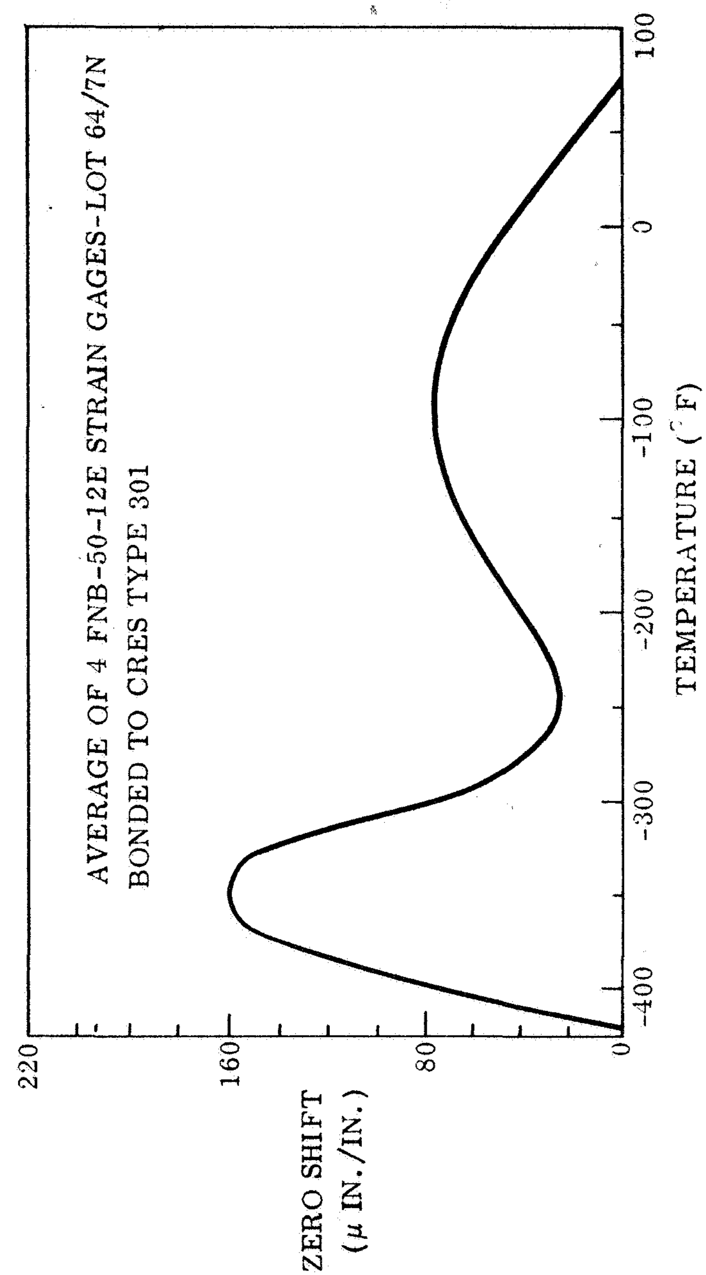


Fig 10 ZERO SHIFT VS. TEMPERATURE



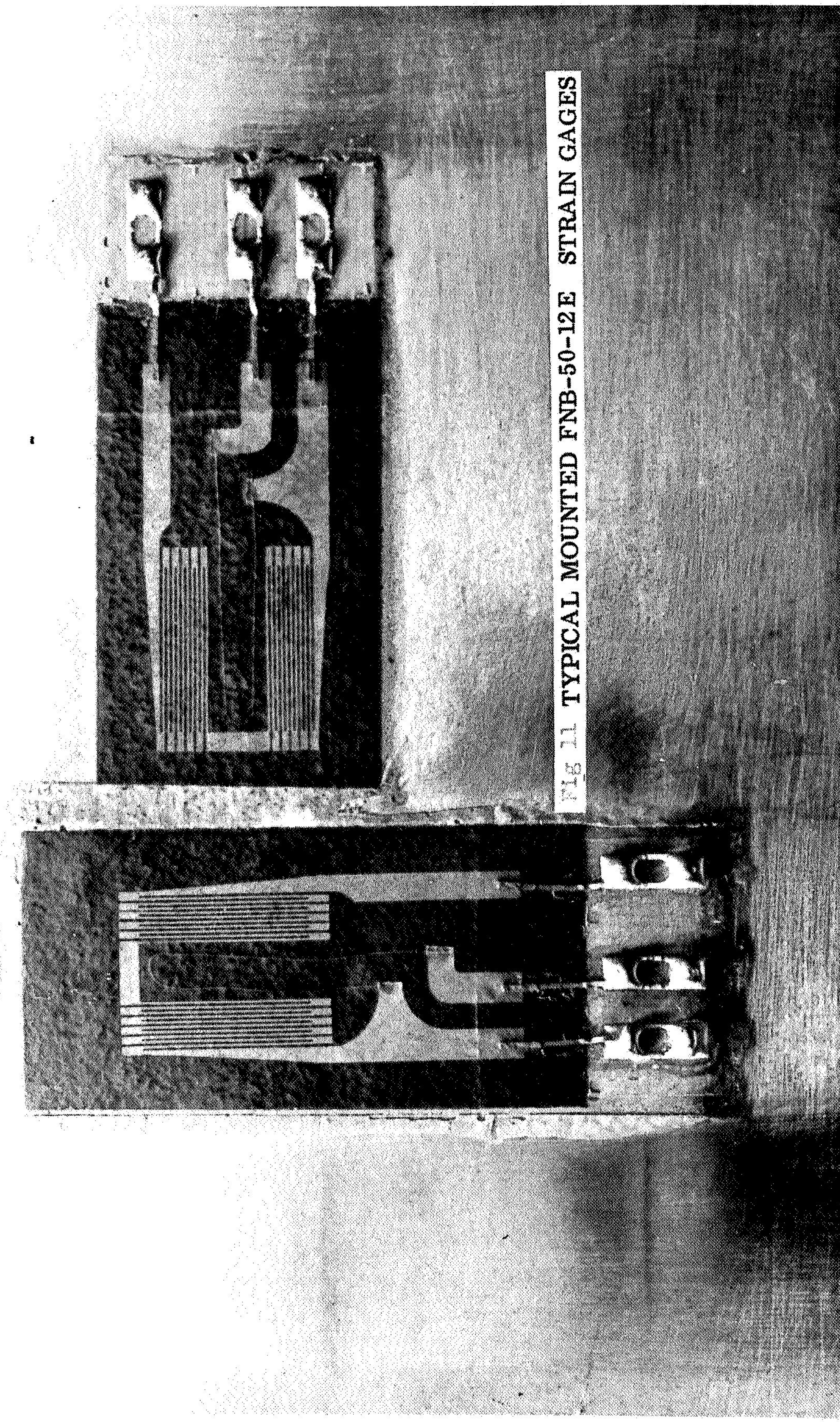


Fig 11 TYPICAL MOUNTED FNB-50-12E STRAIN GAGES

5504053

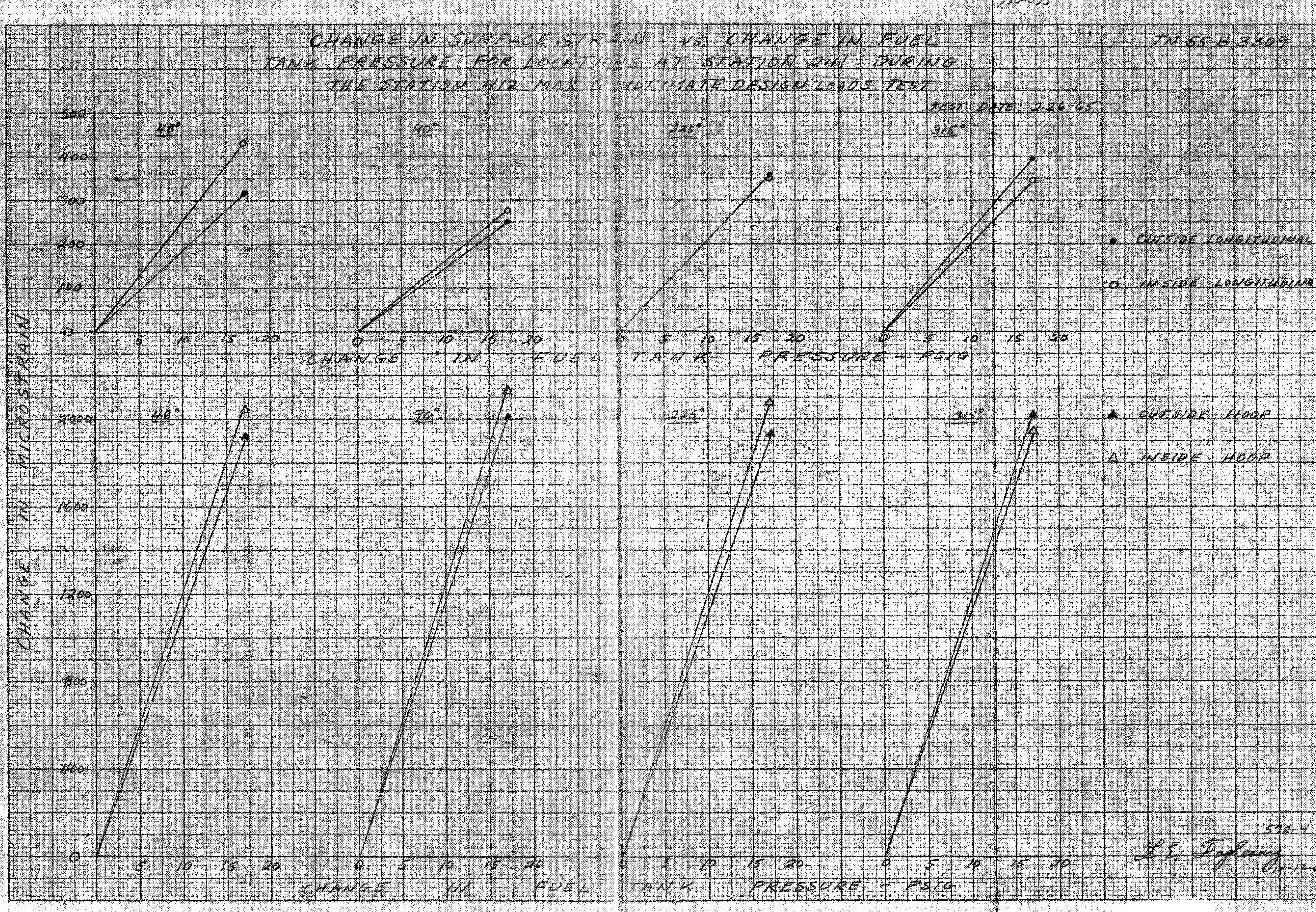
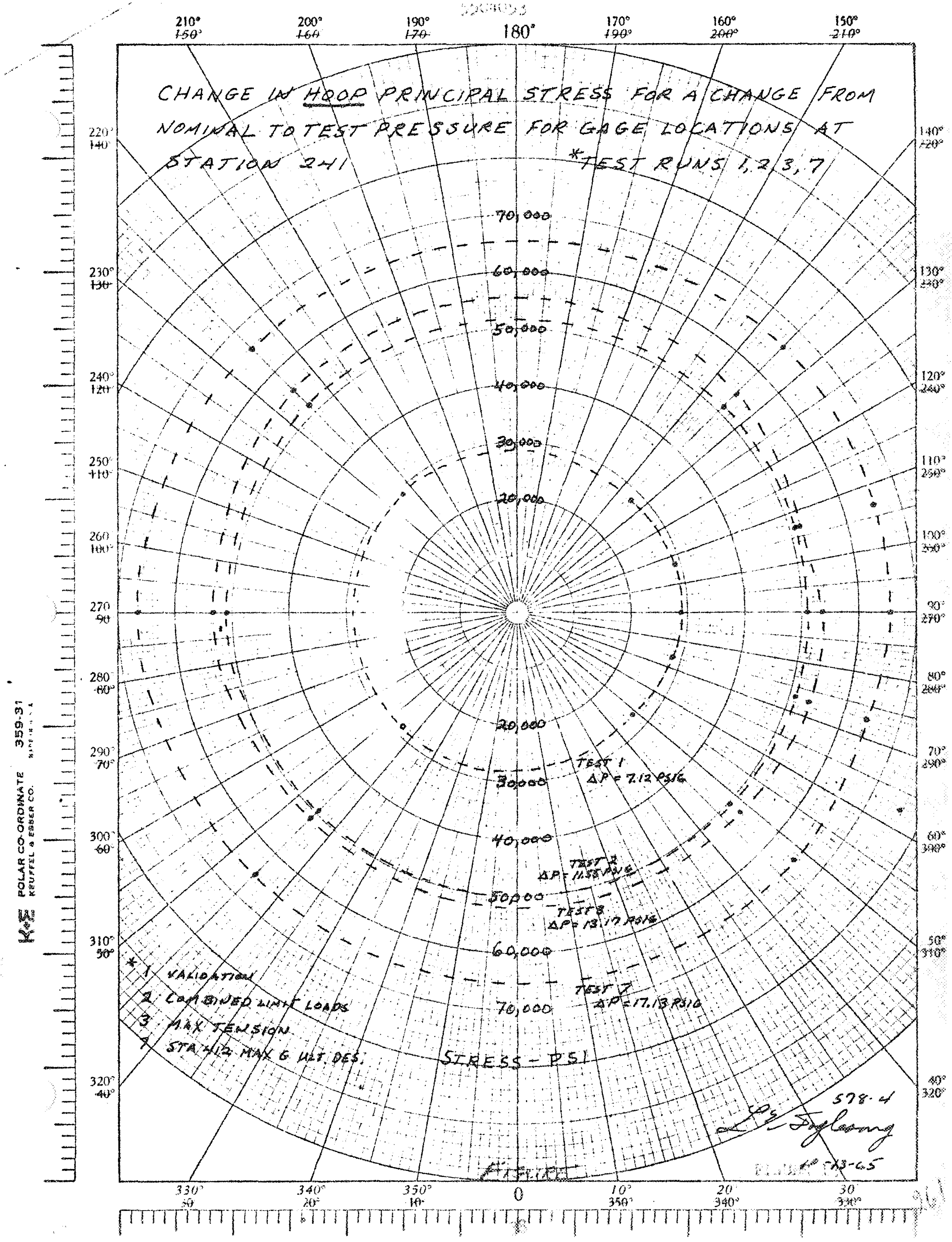
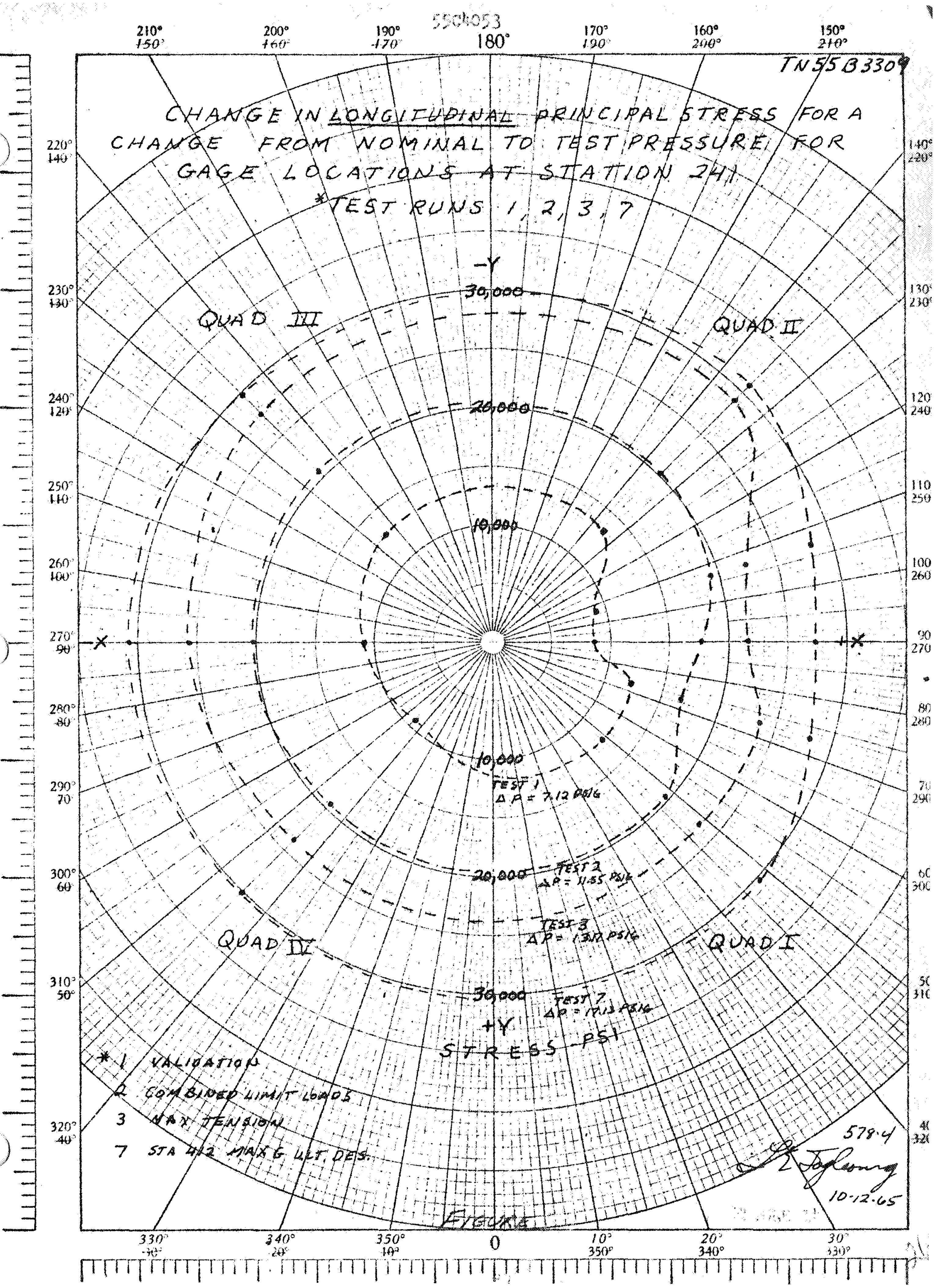


FIGURE 12


CHANGE IN HOOP PRINCIPAL STRESS FOR A CHANGE FROM NOMINAL TO TEST PRESSURE FOR GAGE LOCATIONS AT STATION 241
*TEST RUNS 1, 2, 3, 7
70,000
60,000
50,000
40,000
30,000
20,000
TEST 1 ΔP = 7.12 PSIG
TEST 2 ΔP = 11.58 PSIG
TEST 3 ΔP = 13.17 PSIG
TEST 7 ΔP = 17.13 PSIG
*1 VALIDATION
2 COMBINED LIMIT LOADS
3 MAX TENSION
7 STA 412 MAX G ULT. DES.
STRESS - PSI
578-4
POLAR CO-ORDINATE 359-31
KEUFFEL & ESSER CO.
180°
0


5504053
TN55B3309
CHANGE IN LONGITUDINAL PRINCIPAL STRESS FOR A CHANGE FROM NOMINAL TO TEST PRESSURE FOR GAGE LOCATIONS AT STATION 241
*TEST RUNS 1, 2, 3, 7
-Y
QUAD III
QUAD II
QUAD IV
QUAD I
30,000
20,000
10,000
TEST 1 ΔP = 7.12 PSIG
TEST 2 ΔP = 11.55 PSIG
TEST 3 ΔP = 13.17 PSIG
TEST 7 ΔP = 17.13 PSIG
+Y
STRESS PSI
*1 VALIDATION
2 COMBINED LIMIT LOADS
3 MAX TENSION
7 STA 412 MAX G ULT. DES.
579.4
10-12-65
FIGURE
POLAR CO-ORDINATE 359-31
KEUFFEL & ESSER CO.

5504053

TN 55 B 3309

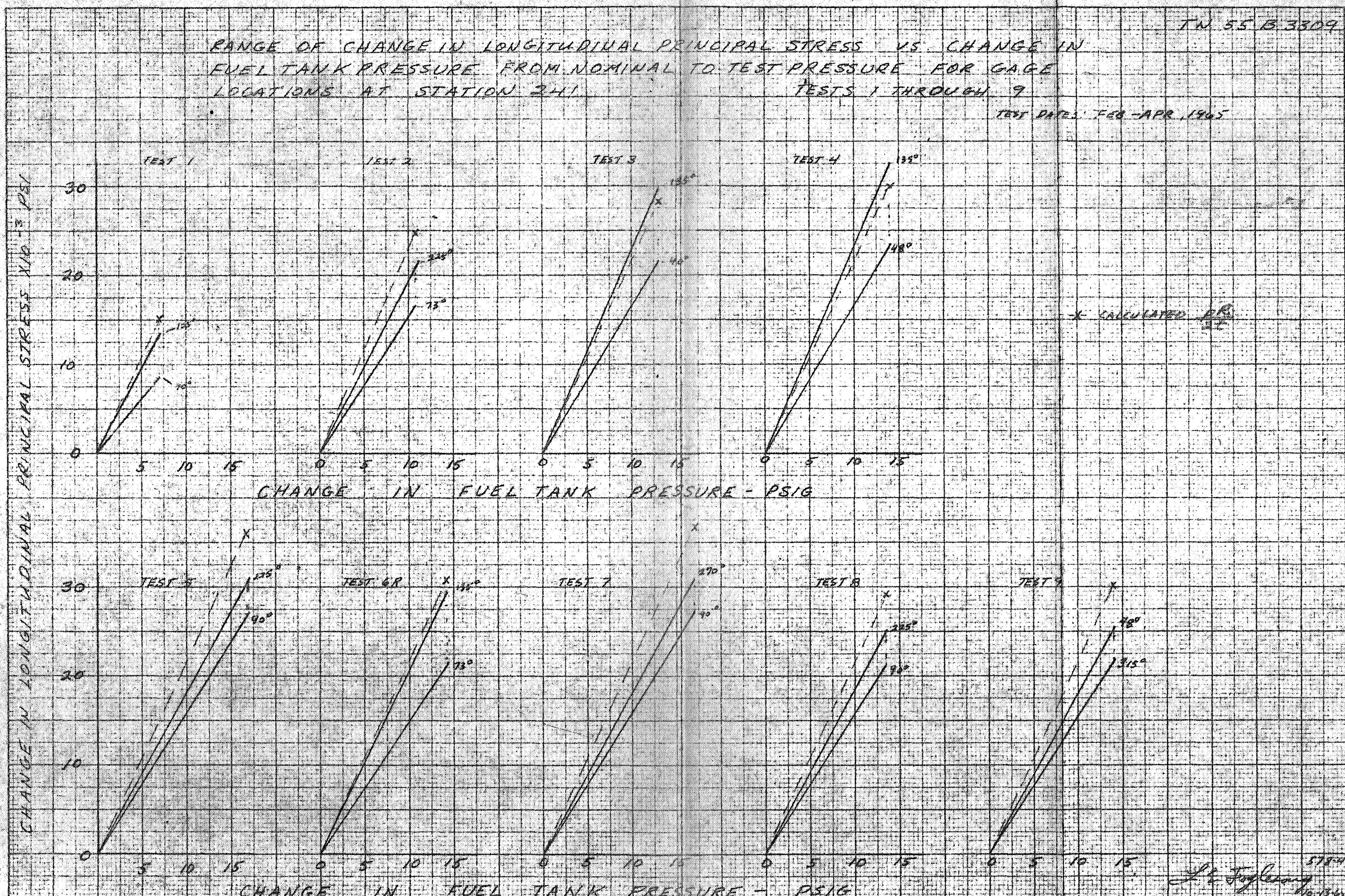
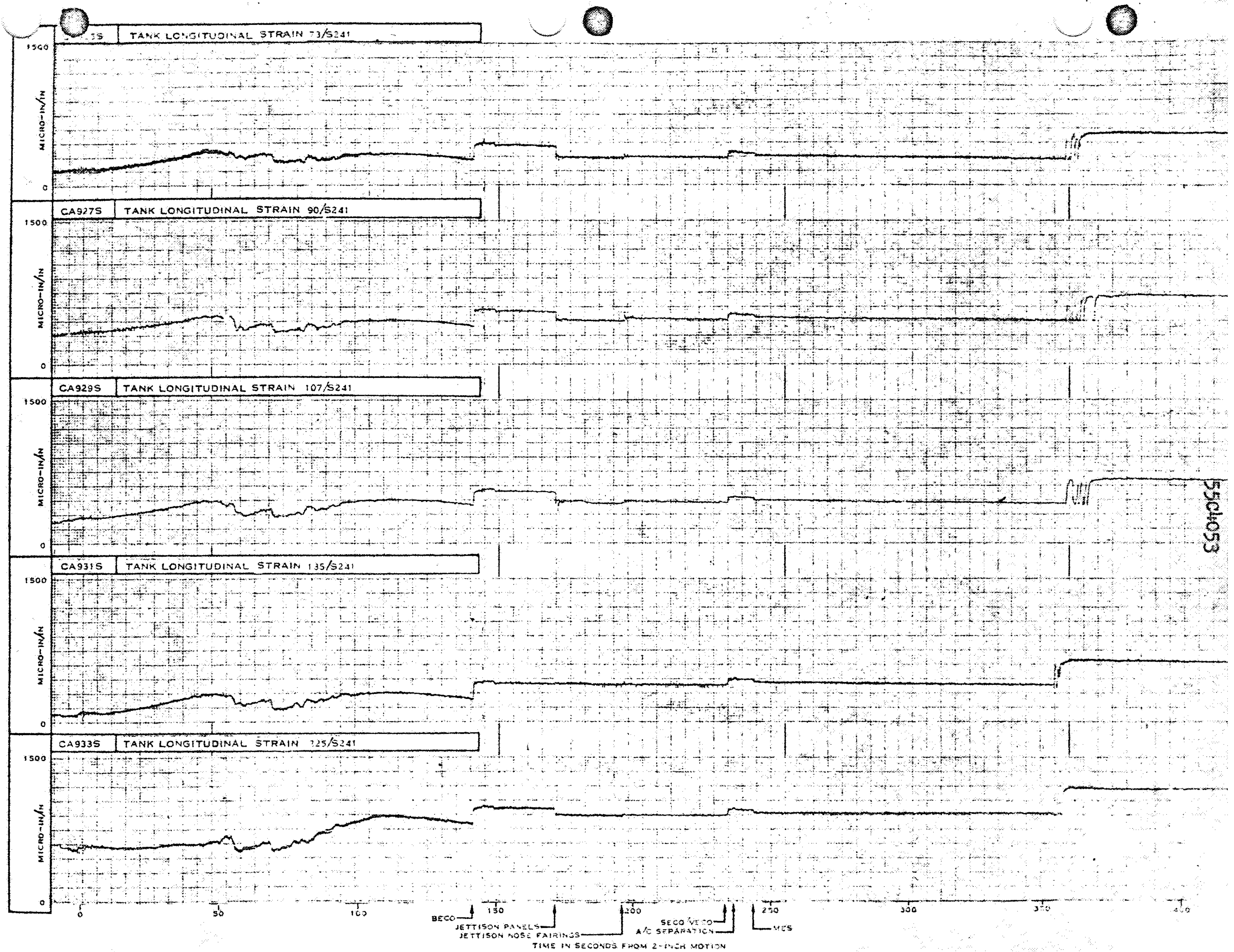


FIGURE 15

40

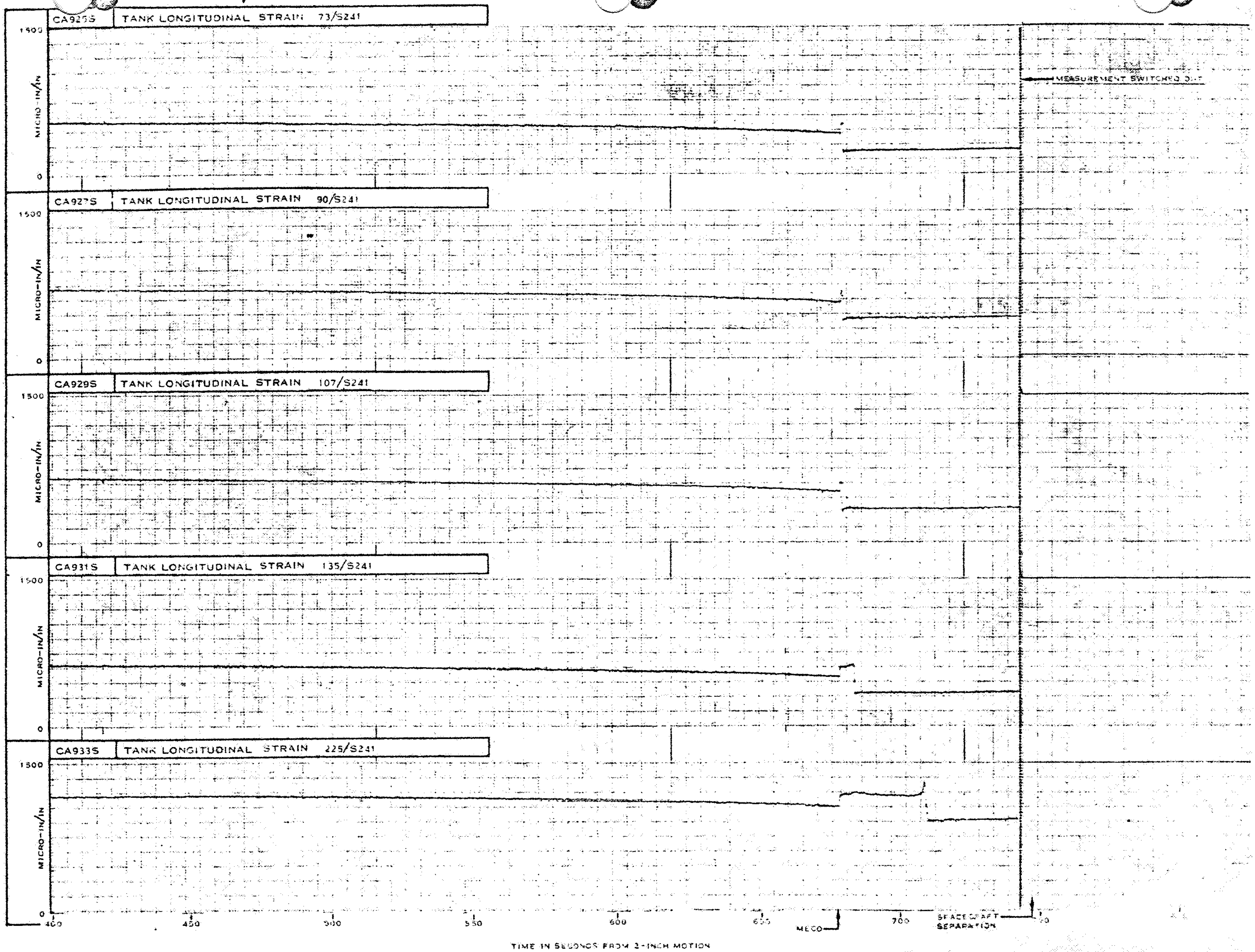


55C4053

4S193ST

Figure 2.10-8. Centaur Fuel Tank Strain Gage Data

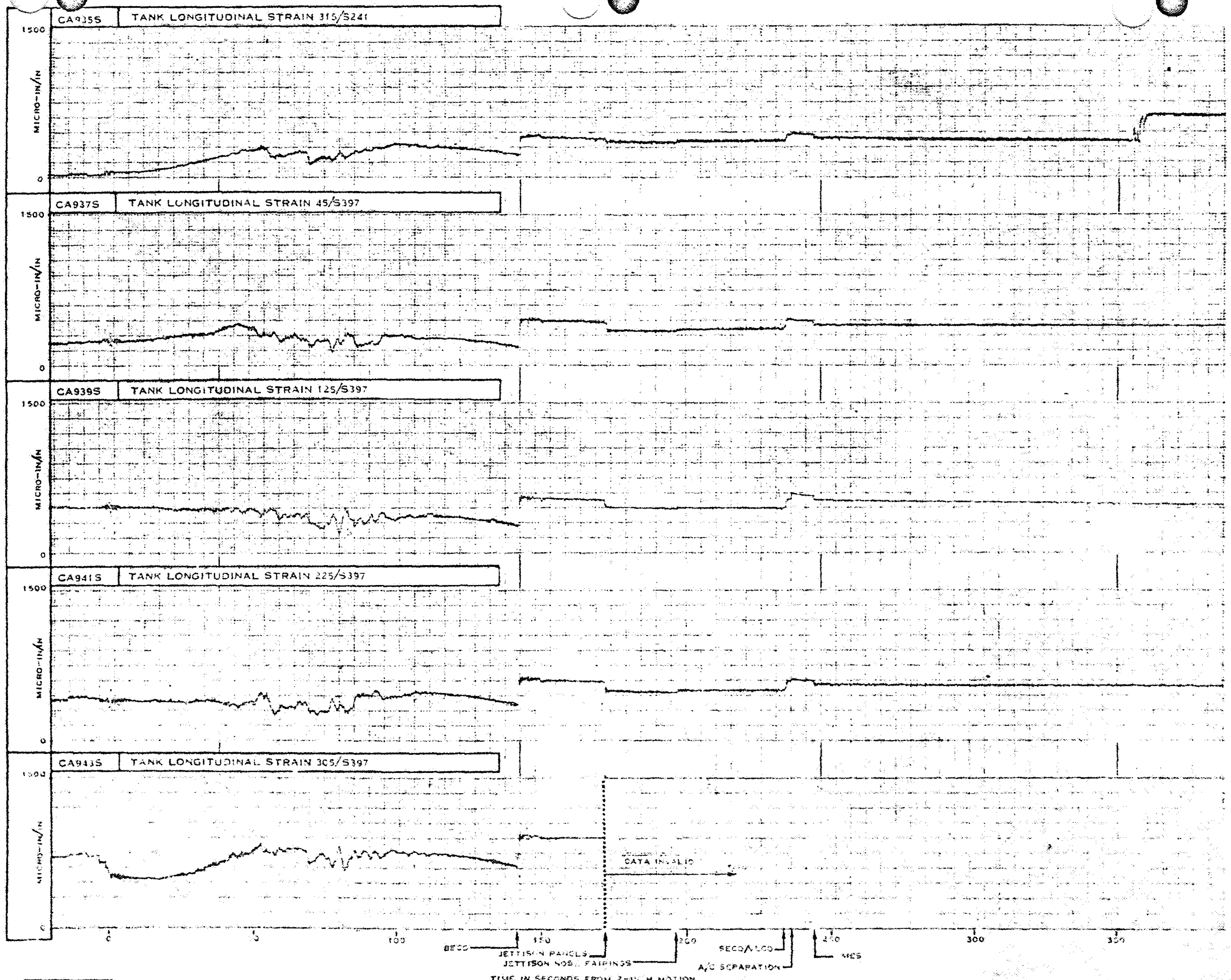
FIGURE 16



4S194ST

Figure 2.10-9. Centaur Fuel Tank Strain Gage Data

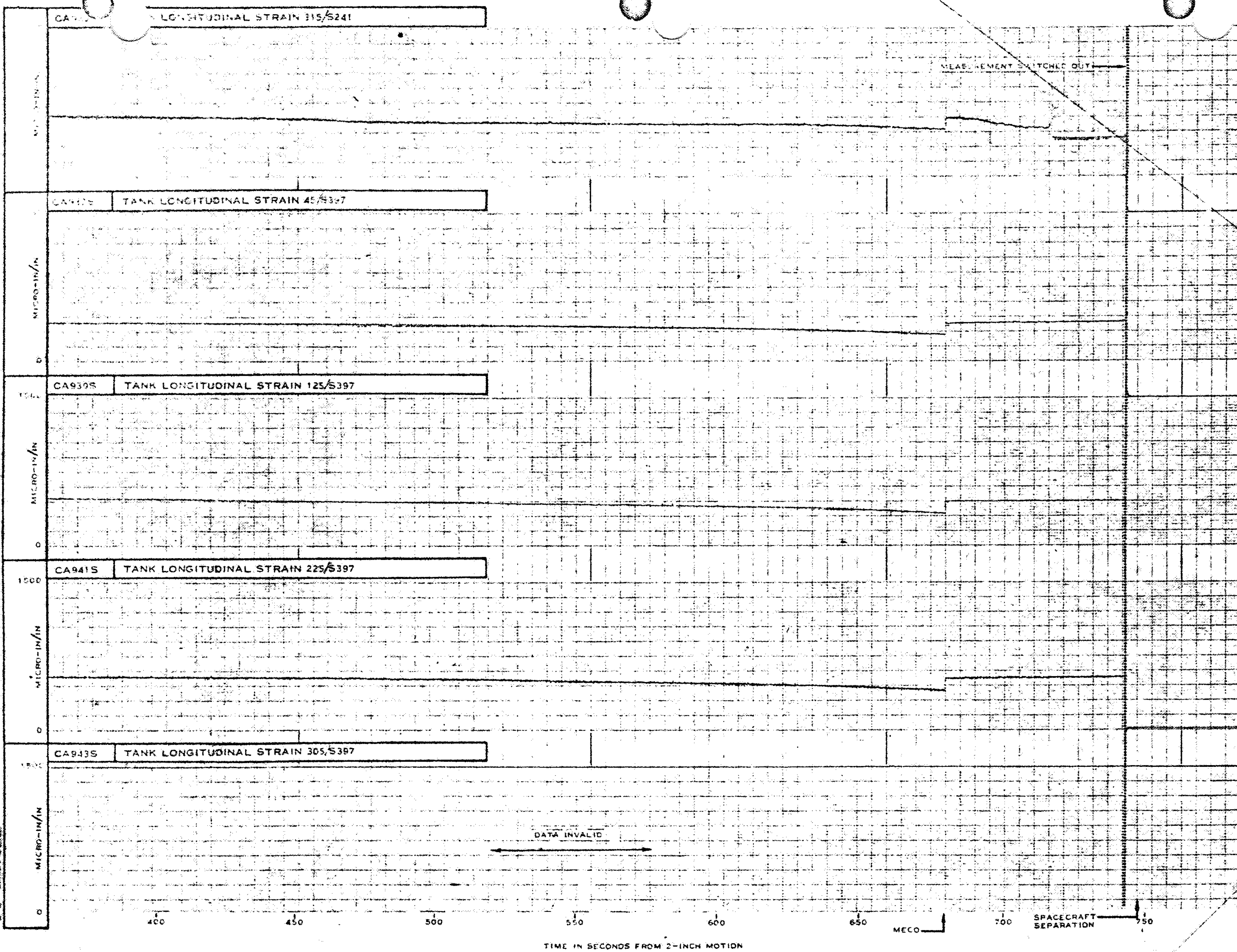
FIGURE 17



4S1955T

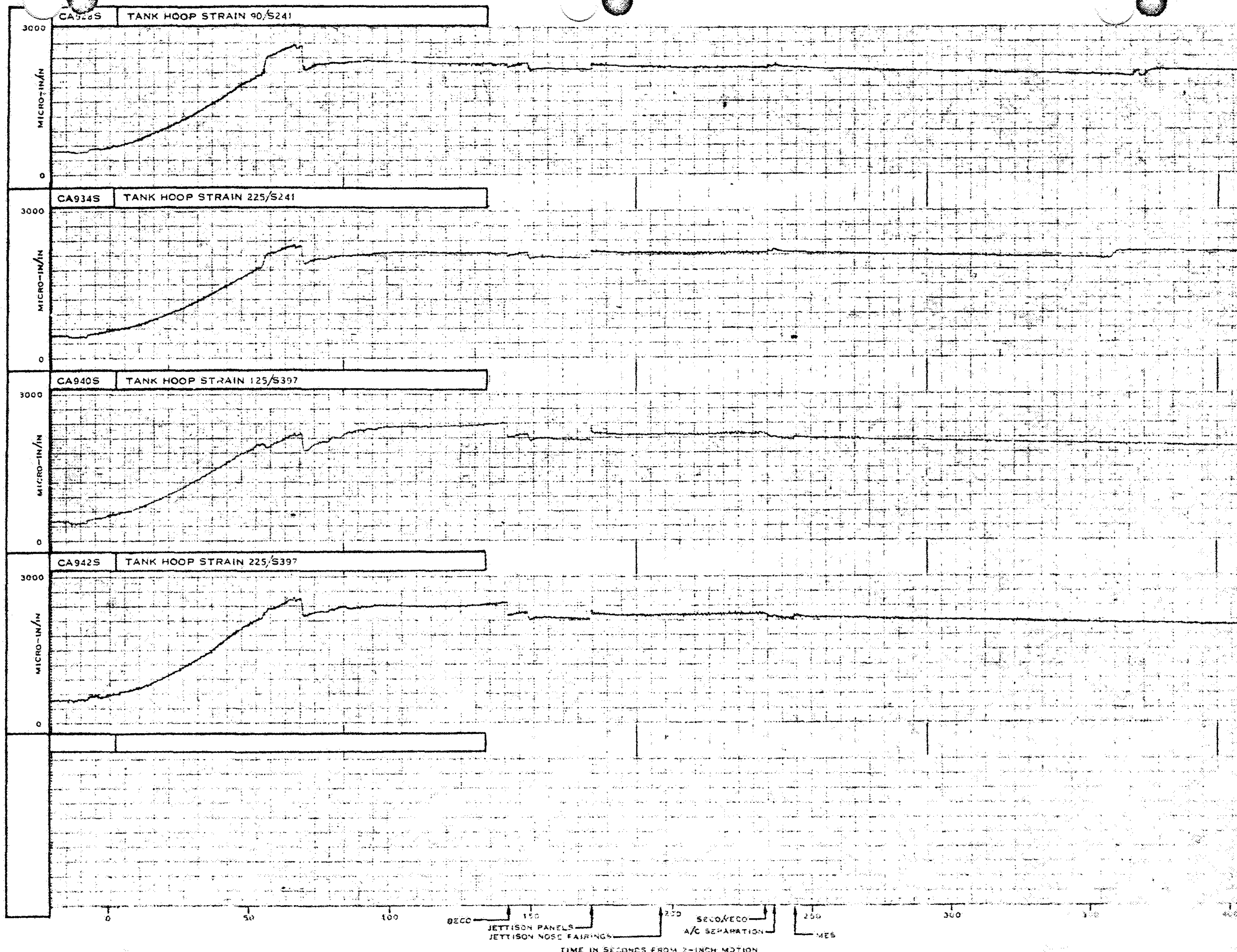
Figure 2.10-10. Centaur Fuel Tank Strain Gage Data

FIGURE 18



4S196ST

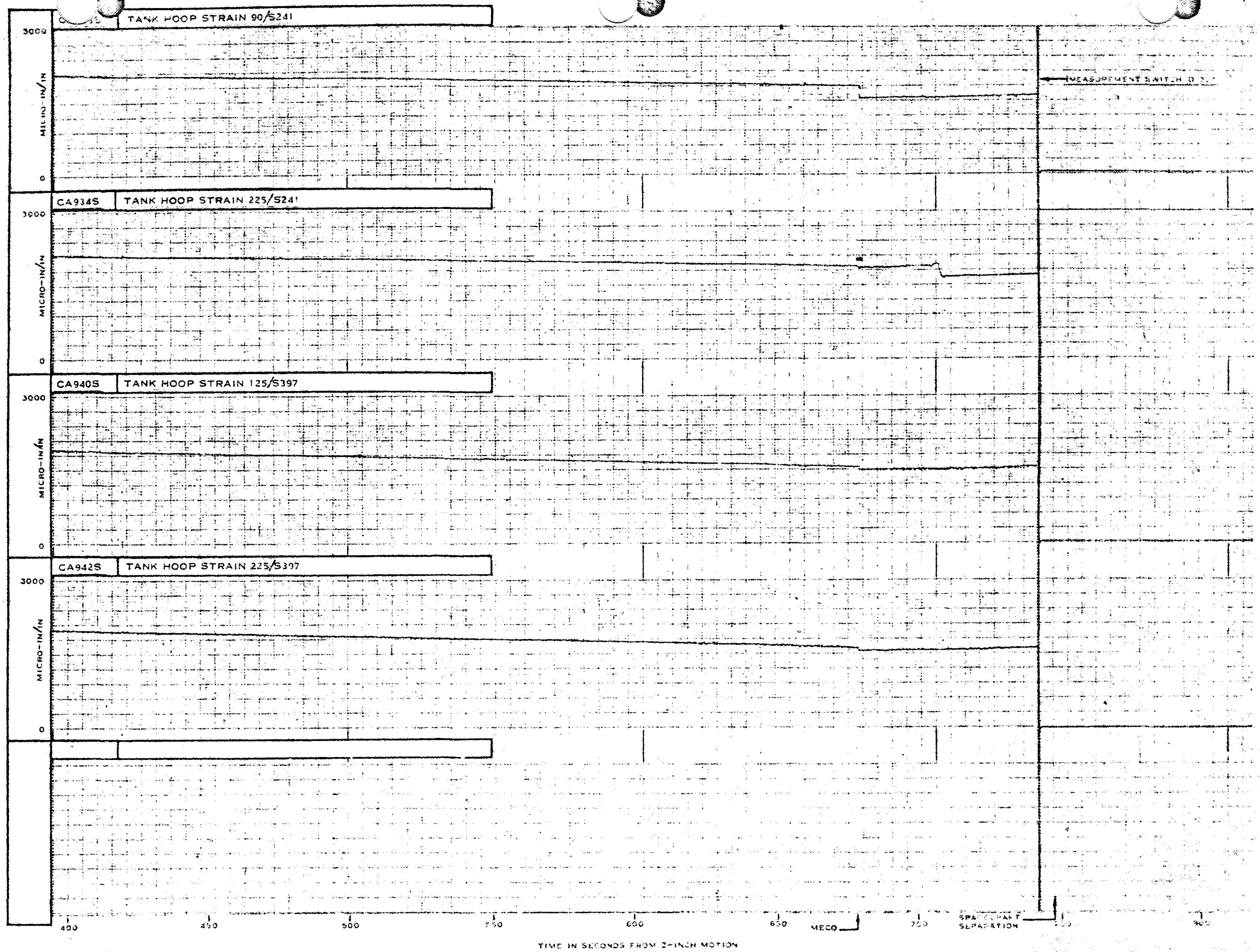
Figure 2.10-11. Centaur Fuel Tank Strain Gage Data



4S197ST

Figure 2.10-12. Centaur Fuel Tank Strain Gage Data

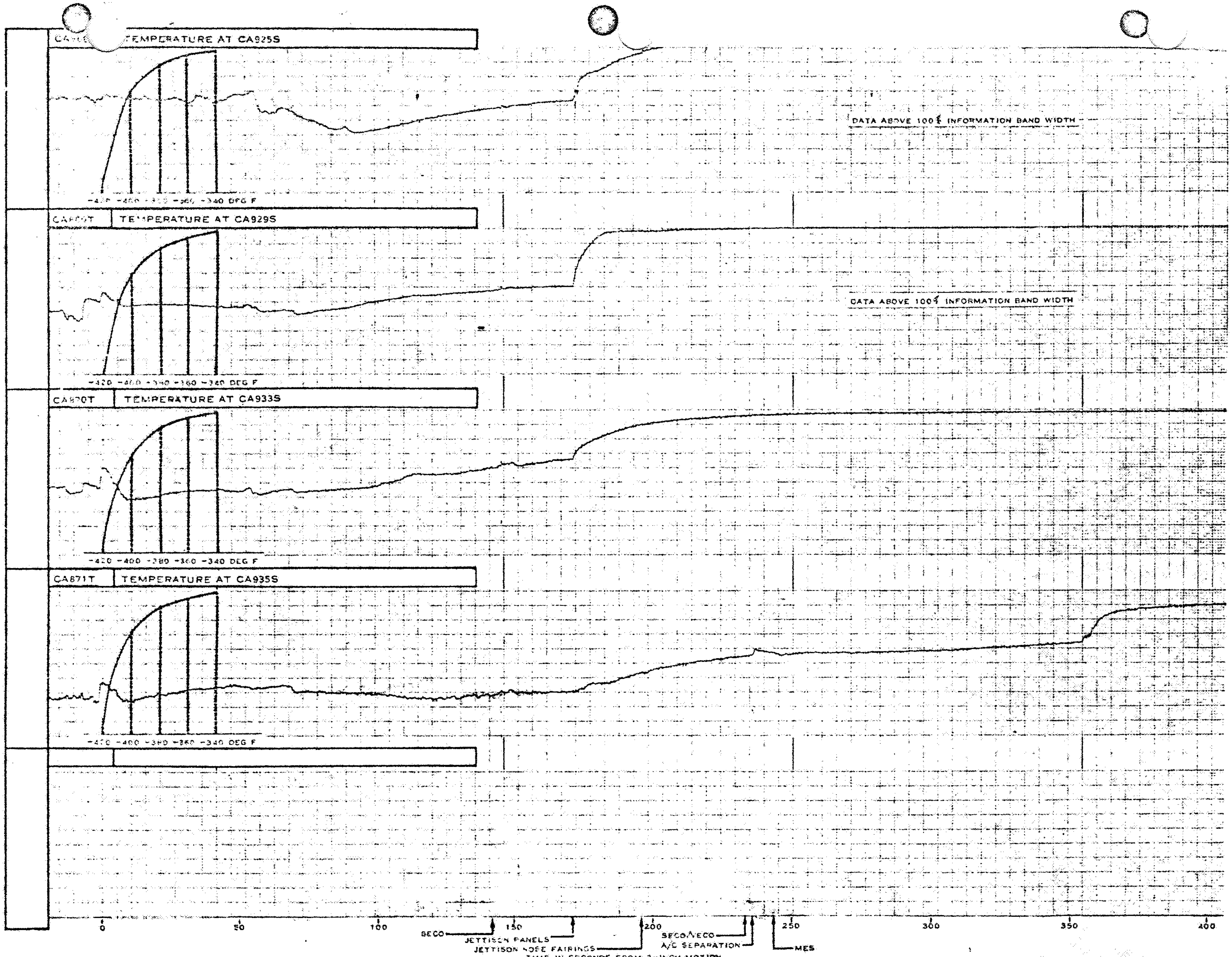
FIGURE 20



4S198ST

Figure 2.10-13. Centaur Fuel Tank Strain Gage Data

FIGURE 21



4S199ST

Figure 2.10-14. Temperature at Strain Gage Locations

APPENDIX A

Program Objectives and Preliminary Planning

For AC-6 Flight Strain Gage Task

Pages 49-55

GENERAL DYNAMICS/ASTRONAUTICS
ML-563-1-64-60
19 May 1964

TO: E. Davies, Dept. 963-4

FROM: Applied Mechanics Section, Materials Test Laboratory, Dept. 563-1

SUBJECT: Program Objectives and Preliminary Planning for AC-6 Flight Strain Gage Evaluation

The program outlined below is planned to provide the essential basic strain gage and material property information to interpret AC-6 flight data.

The program results will supplement available data (NASA, GD/A and published literature) and not duplicate them, since objectives are specific for one material and one strain gage installation. Experience will be gained which will be applicable to future programs, however.

Flight strain gages are intended to satisfy the following objectives:

1. Measure bending and thrust load in the fuel tank skin at two stations.
2. Measure hoop stress in the seal plate ring at station 412.
3. Demonstrate the capability for obtaining strain measurement from flight vehicles.

Success in satisfying the objectives depends on the following things as well as close cooperation of the many departments involved and monitoring by Dept. 563-1 strain gage people through the writing of the final report.

1. Strain gage installation reliability.
2. Careful handling of strain gage areas.
3. Careful checkout of electrical system to avoid high voltage across the gage.
4. Particular attention to calibration procedure to get realistic scale factors for data reduction.

Success in satisfying objectives 1 and 2 will depend on certain experimental values which will result from the laboratory program and on several other flight measurements.

If the elastic constants E_1, E_2, μ_1, and μ_2 are determined for the material in questions, stress can be calculated. See the Appendix for other measurements needed and an estimate of errors. Local stress conditions must be eliminated where possible (insulation panel spacer pads) or carefully evaluated.

Success in satisfying objective 2 will depend on experimental values for the strain gages and published values for the material properties. No station 412 seal plate material is available for test. Some strain gage information on similar materials will be obtained. Some assumptions will be necessary about the stress field under the strain gages since all gages will measure the difference in principal strains.

Program Outline

The program will consist of the following parts which will be required for preparation of a factual flight report.

I. Examine analytical method for flight data use.
II. Laboratory testing to determine strain gage characteristics and material properties.
III. Point Loma test coordination to check procedures and assumptions.
IV. Surveillance of flight strain gage effort.
V. Preparation of reports to document laboratory and test vehicle results.
VI. Assist with flight data analysis report preparation.

Part I has been partially accomplished by Stress Dept. 557-1 and will be their responsibility. They will also be responsible for an error analysis report and the flight analysis report (Part VI). The Materials Test Laboratory Applied Mechanics section will co-author the error analysis report and the flight data analysis report.

Parts II, III, IV and V will be the responsibility of the Applied Mechanics section of Dept. 563-1. The following is an outline of this work.

Part II Laboratory Testing:

a. Strain Gage installation procedure checkout on laboratory samples.
b. Transverse sensitivity determination for strain gages.
c. Strain gage sensitivity determination (3 temperatures).
d. Temperature effect on zero shift.
e. Material properties for tank material.
f. Effect of strain level on gage factor.
g. Output of strain gage installation on biaxial stress field using an existing 0.016" wall tank.

Part III Point Loma Testing:

A duplication of the flight installation will be made on EID 55-7545-1. Predicted strain levels (skin) will be compared to actual test data to determine the accuracy of the predicted values which are based on laboratory test results. Where strain values are not predictable (rings) the test data will be examined for credibility in light of other measurements available in the structural test program (deflections, etc.). Pressure cycles with and without panels will be run to check the panel influence.

Program Outline - continued

Part IV Flight Instrumentation Surveillance

This will be an effort to assist with instrumentation design and calibration procedures to insure best accuracies of the final data. Also, an effort will be made to double check for possible problem areas in the strain gage pre-flight checkout program. An end to end calibration will be accomplished at AMR, including pressure cycles with and without insulation panels, at room temperature and with panels at LH_2 temperatures. Tank strain gages will also be monitored before and after insulation panel installation at AMR.

Part V Test Laboratory Reports

The objective here will be to present the laboratory data and how it was used in conjunction with EED 55-7545-1 results to establish the accuracies to be expected in the flight data analysis report.

VI Flight Data Analysis Report

This will be the application of all previously established material and strain gage properties to the task of reducing the flight data from numbers to structural behavior of the AC-6 vehicle.

Appendix

Estimate of Errors

Prepared by: ____________________
L. E. Foglesong, Test Lab Engr.

Prepared by: D. J. Ferris 5-21-64
D. J. Ferris, Sr. Test Lab Engr.

Approved by: W. M. Gross
W. M. Gross
Test Laboratory Group Engineer

cc:	F. Dittoe	557-10
	P. Johnson	963-30
	F. Wallace, Jr.	565-1
	W. Sutherland	966-4
	C. Spurlin	NASA
	J. Hughes	966-00
	D. Ferris	563-10
	563-1 Files	(2)

APPENDIX

PRELIMINARY ESTIMATE OF ERRORS IN ANALYSIS OF AC-6 FLIGHT STRAIN GAGE DATA

Skin Stress Determination:

$$\sigma_1 = \frac{E_1}{1-\mu_1\mu_2}(e_1 + \mu_2 e_2) \quad \ldots \quad (1)$$

$$\sigma_2 = \frac{E_2}{1-\mu_1\mu_2}(e_2 + \mu_1 e_1) \quad \ldots \quad (2)$$

$$e_1 = (mv/v)_{OUT} \cdot SF - K_T \quad \ldots \quad (3)$$

$$e_2 = (mv/v)_{OUT} \cdot SF - K_T \quad \ldots \quad (4)$$

$$E_1 = \frac{F}{Ae}$$ .... (Experimental) .... (5)

$$E_2 = \frac{F}{Ae}$$ .... (Experimental) .... (6)

$$e = \frac{mv/v}{GF_{EXP}}$$ .... (Strain in Eq. 1 and 2) .... (7)

$$\mu_1 = \frac{(mv/v)_T - (mv/v)_L \cdot S_T}{(mv/v)_L} \quad \ldots \quad (8)$$

$$\mu_2 = \frac{(mv/v)_L - (mv/v)_T \cdot S_T}{(mv/v)_T} \quad \ldots \quad (9)$$

$$S_T = \frac{(mv/v)_A}{(mv/v)_B}$$ .... (Transverse sensitivity of strain gage in Eq. 8) .... (10)

$$GF_{EXP} = \frac{GF_{SET} \cdot e_{RDG}}{e_{ACT}}$$ .... (Experimentally determined gage factor for Eq. 7) .... (11)

.... (Seal plate flight strain reading) .. (12)

(13)

reduces to (14)

Quantity	Description	Source	Comments	Error
K_T	Strain due to temperature drift	Experimental tests		
mV/V	Strain indicator output	Mat'ls Prop Tests		± 0.1%
$(mV/V)_A$	Indicated strain from strain gage mounted at right angles to the strain in a uniaxial strain field	Strain indicator reading		± 0.1%
$(mV/V)_B$	Indicated strain from strain gage (similar to gage above) mounted in the direction of strain in a uniaxial strain field	Strain indicator reading		± 0.1%
$(mV/V)_T$	Indicated strain from transverse strain gage on transverse grain material property specimen	Strain indicator reading		± 0.1%
$(mV/V)_L$	Indicated strain from longitudinal strain gages on transverse grain direction material property specimen			± 0.1%
S_T	Transverse sensitivity of strain gage	Calculated from experimental data.		± 1.0%
SF	Scale factor for data reduction	Calibration of strain gages on missile	Depends on strain gage sensitivity which in turn is based on an estimated temperature	± 5.0%
t	Skin thickness	Quality Assurance Records		± 1.0%
μ_1	Poisson's ratio in transverse grain direction of missile skin	Calculated from experimental data		
$(MV/V)out$	Strain gage circuit output	Telemetry	(Depends on calibration techniques and data processing accuracy)	±10.0%

Quantity	Description	Source	Comments	Error
A	Area of material prop. specimen	Measured with micrometer		± 0.5%
e	Strain in material prop. specimen	Calculated by strain indicator		---
e_1	Strain in skin parallel to flight			
e_2	Tank skin hoop strain			
e_{ACT}	Actual strain under strain gage during gage factor determination test	Calculated from beam geometry		1.0%
e_{RDG}	Strain reading on SR-4 indicator for given strain during gage factor determination test			0.1%
E_1	Modulus of Elasticity in transverse grain direction of missile skin	Calculated from experimental data		---
E_2	Modulus of Elasticity in longitudinal grain direction of missile skin	Calculated from experimental data		
F	Load applied to material prop. specimen	Load Cell	Depends on load cell accuracy	± 0. ± 1.0%
GF_{EXP}	Gage factor of strain gages used in material properties tests	Experimental		± 1.0%
μ_2	Poisson's ratio in the direction of rolling in the missile skin	Calculated from experimental data		
σ_1	Skin stress in direction parallel to flight			
σ_2	Skin hoop stress			

STATION 412 SEAL PLATE RING STRESS DETERMINATION

$$(e_2 - e_3) = (mv/v)_{OUT} \cdot SF \quad \text{. . . . (Seal plate flight strain reading) . .} \quad (12)$$

$$(e_2 - e_3)_{ACT} = \frac{\sigma_2}{E_2}(1+\mu_2) - \frac{\sigma_3}{E_3}(1+\mu_3) \quad \text{. .} \quad (13)$$

reduces to $(e_2 - e_3)_{ACT} = \frac{\sigma_2}{E_2}(1+\mu_2)$ when $\sigma_3 = 0$ . . (14)

All errors shown above will apply (radial stress σ_3 is assumed to be zero).
No temperature drift correction will be made for the station 412 strain gages.

Quantity	Description	Source	Comments	Error
E_2	Modulus of Elasticity of ring material in the hoop direction	Mat'ls Research Literature		± 5%
μ_2	Poisson's ratio in the hoop direction	" "		± 5%

APPENDIX B

Strain Gage Program T.D. 126

Strain Gage Selection

Page 57

GENERAL DYNAMICS/ASTRONAUTICS
ML-563-1-64-45
15 April 1964

C
O
P
Y

TO: J. A. Hughes, Dept. 963-1

FROM: Applied Mechanics Section;
Materials Test Lab, Dept. 563-1

SUBJECT: Strain Gage Program T.D. 126

The following information was requested by you 9 April 1964 to support design release. It represents our current opinion which will be substantiated by further evaluation work as funded by WAP K201038 (pending revision to increase Dept. 756 hours).

Strain Gage Selection and Procedure:

For all tank strain gages use Baldwin FNB-50-12E type with Budd Co. GA-5 cement. Use Budd Co. No. 3 strain gage terminals and GA-5 for cement and waterproofing. Install per engineering direction (Ref. Procedure No. ML-563-1-64-43) which will include all required checkout and measurements and recordings of the strain gages and harness to the first plug in the system.

For the four seal plate locations at station 412 use Budd Co. C12-121-R2B rosettes, No. 3 terminals and GA-5 for cement and waterproofing. Install per engineering direction (Ref. Procedure No. ML-563-1-64-44) as above.

A Program Objectives Memo will be prepared as soon as possible to clearly show our planned activity on this task. Items for our early action are:

1. WAP revision to Dept. 756 line 13 to increase hours to cover R&D work (total 1000 hrs).

2. Circuit constant determination for Le RC design of signal conditioning equipment.

3. Procurement of FNB-50-12E gages for evaluation work and early tank installation if production procurement is stalled.

Prepared by: D. J. Ferris
D. J. Ferris, Sr. Test Lab Engr.

Approved by: ______________________
W. M. Gross, Test Lab Group Engr.

cc:	F. Dittoe	591-1
	P. Bunch	966-40
	E. Davies	963-40
	W. Sutherland	966-40
	C. Spurlin	NASA

APPENDIX C

Strain Gage Program T.D. 126

Results of Material Properties Tests and

FNB-50-12E Strain Gage Evaluation

Pages 59-66

	578-4-M-65-82
DATE	22 June 1965
TO	E. H. Davies, Centaur Instrumentation, Dept. 963-4
FROM	Stress Measurements - Electrical Test Laboratory, Dept. 578-4
SUBJECT	Strain Gage Program TD-126, Results of Materials Properties Tests and FNB-50-12E Strain Gage Evaluation
REFERENCE	(A) Witzell, W. E., "ZZL-64-028, Poissons Ratio and Modulus of Elasticity for 301 XFH Strainless Steel at 70°F, -320°F, and -423°F" dated 13 August 1964.
	(B) Memo 578-4-M-65-72, Subject: Evaluation of Characteristics of Type FNB-50-12E Strain Gages Bonded to 301 CRES at Temperatures between 75° and -423°F.
ENCLOSURE	(1) C9-121-R2B Strain Gage % Change of Gage Factor vs. Temperature
	(2) Modulus of Elasticity and Poissons Ratio 301 XFH Stainless Steel
	(3) FNB-50-12E Strain Gage % Change of Gage Factor vs. Temperature
	(4) Typical Thermal Output vs. Temperature

INTRODUCTION:

This memorandum gives the results of the peripheral tests. All of such tests are now completed. The information contained is also required for the computer program to be used for the flight stress, moment and load calculations which are determined from the telemetered strain data.

MATERIAL PROPERTIES:

Objectives:

To obtain the modulus of elasticity and Poissons ratio of 301 XFH stainless steel at room temperature, -320°F, and -423°F in both the longitudinal and transverse grain directions.

Material:

Test specimens were fabricated from 301 XFH stainless steel, thickness 0.014 in., heat 71583, and coil 1741-AZ. This material is the same material used in the AC-6 tank to which the strain gages are bonded.

Material: (Contd)

The test specimens were standard 1/2 in. wide tensile coupons 11 in. long. Four each of the longitudinal and transverse grain orientations were manufactured.

Instrumentation:

Specimens were instrumented with C9-121-R2B strain gages bonded to the material with 6A-5 cement. The gages were placed opposite to one another on each side of a specimen. Gages were wired through a switch box that permitted individual readout of the longitudinal and transverse gages on the specimen. The gages were wired into a full bridge of two resistors and two active gages which averaged out bending. All gages were of the same gage factor and lot number so that the only correction necessary for reading was a temperature correction for gage factor.

Procedure:

1. The specimens were placed inside a cryostat and fitted to end clevises of a Tinius Olsen testing machine.
2. For cryogenic tests, cryogenic fluid was admitted to the cryostat. LN_2 and LH_2 were used to obtain temperatures of -320°F and -423°F, respectively.
3. Loads were applied in 100-lb. increments to 600 lbs. Strains were recorded for each load increment.

Difficulty was encountered in running specimens at LH_2 temperature. Tests for this temperature were run three times to verify data. The difficulty was apparently gage heating which produced small bubbles over the surface of the gage and this in turn created turbulence which gave unstable readings. This particular area should be further investigated and is a problem area for future testing.

Gage Factor Variation with Temperature:

Tests were conducted using a NASA beam fixture to determine the gage factor changes of the C9-121-R2B gage with temperature. The results of these tests are shown in Enclosure (1).

The correction is applied as follows:

$$\text{Actual Strain} = \frac{\text{G.F. at room temperature}}{\text{G.F. set} \times \text{correction factor}} \times \text{indicated strain}$$

This correction was used in the calculation of the modulus of elasticity but was not required for Possions ratio. Transverse sensitivity was not corrected as it amounted to less than 1%.

Results:

The results are given in Enclosure (2).

The average values based on four specimens each in the longitudinal and transverse grain directions are:

Temperature	Grain Direction	Modulus PSI	Poisson's Radio
Ambient	Longitudinal	26.4×10^6	-.272
	Transverse	30.0×10^6	-.312
-320°F	Longitudinal	30.1×10^6	-.280
	Transverse	33.9×10^6	-.313
-423°F	Longitudinal	30.2×10^6	-.298
	Transverse	33.3×10^6	-.326

The theory for an anisotropic material shows that the relationship between Poisson's ratio and the Modulus of Elasticity is a constant or

$$\frac{\mu_L}{\mu_T} = \frac{E_L}{E_T}$$

The above ratio's are compared below based on the average values.

Room temperature	$\frac{\mu_L}{T} = .872$	$\frac{\mu_L}{T} = .880$
-320°F	= .895	= .888
-423°F	= .914	= .907

The maximum variation is approximately 1% which is in good agreement with the theory.

FNB-50-12E STRAIN GAGE EVALUATION:

Gage Factor Variation with Temperature:

Tests were conducted using a NASA beam fixture to determine the gage factor changes with temperature. The results of these tests are given in Enclosure (3).

FNB-50-12E STRAIN GAGE EVALUATION: (Contd)

Installation Check:

Four tensile coupons were mounted on the AC-6 tank adjacent to the areas where gages were being installed on the tank. FNB-50-12E gages were installed on the coupons at the same time and under the same conditions as the gages installed on the tank.

The coupons were then immersed in LH_2 and tensile loaded until 5500 micro in./in. strain was measured with the SR-4 Strain Indicator. The strain gages were then observed for unbonding and cracking. None was found. Therefore, the tank strain gage installation is considered to be good for -423°F strain measurements.

Thermal Strain Due to Temperature:

Tests on the FNB-50-12E gage were conducted by D. K. Neff, 573-4, to determine the strain unbalance due to temperature. The gages used were of the same lot number and gage factor as those used on the Centaur tank. The work done is reported in Reference (B). Enclosure (4) shows the results of Reference (B).

PREPARED BY E. K. Winslow

CHECKED BY D. J. Ferris 7-27-5

APPROVED BY R. E. Bailey
Test Lab Group Engineer
Electrical Test Laboratory

Distribution:

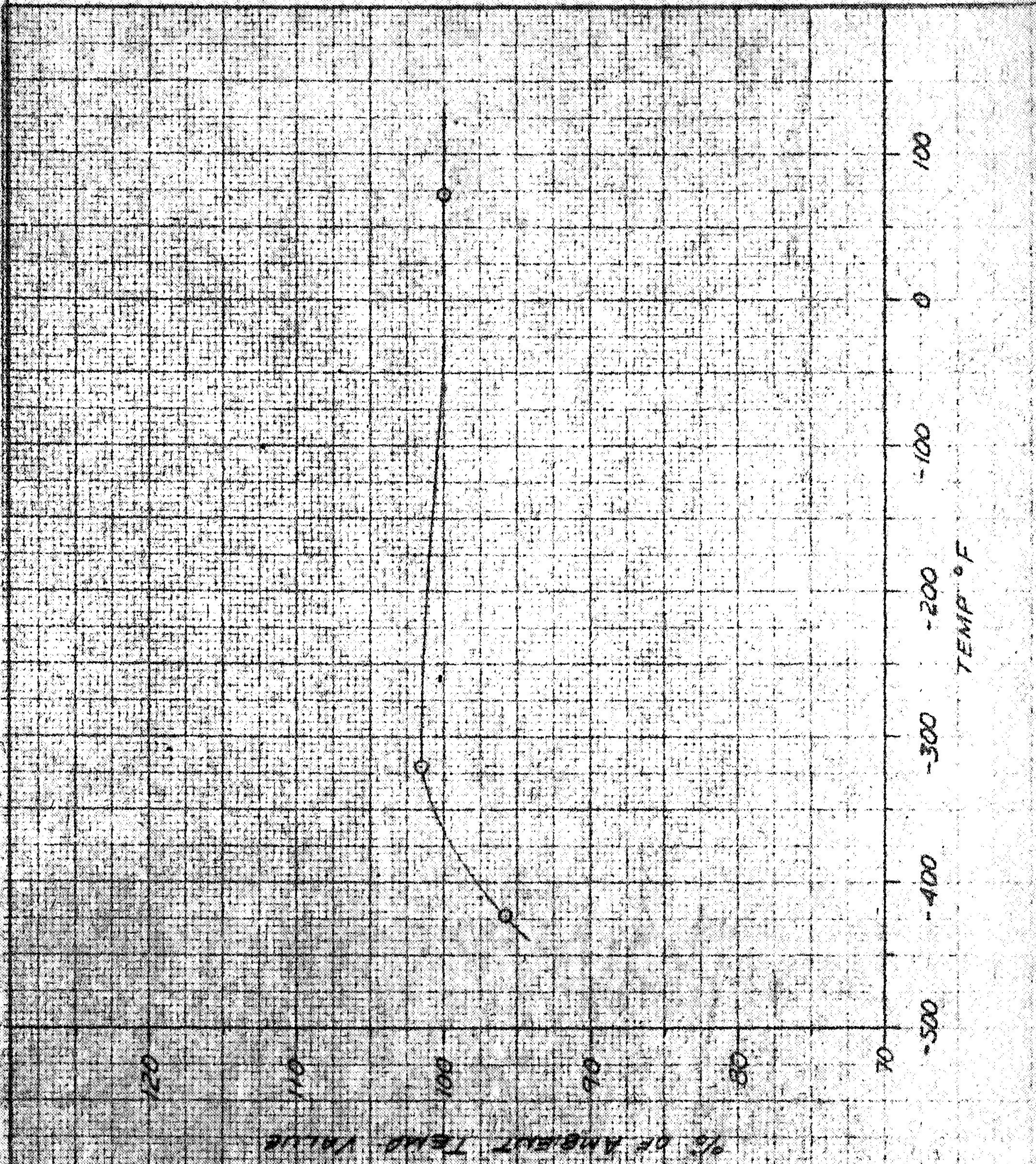
K. Lehman 963-6 (3)
F. Dittoe 557-1 (2)
J. Hughes 963-1 (2)

CONVAIR ASTRONAUTICS

REPORT

PAGE

C9-121-R2B STRAIN GAGE
% CHANGE OF GAGE FACTOR vs. TEMP.



PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE
E.K. WINSLOW	5-7-65				

FORM NO. [illegible]

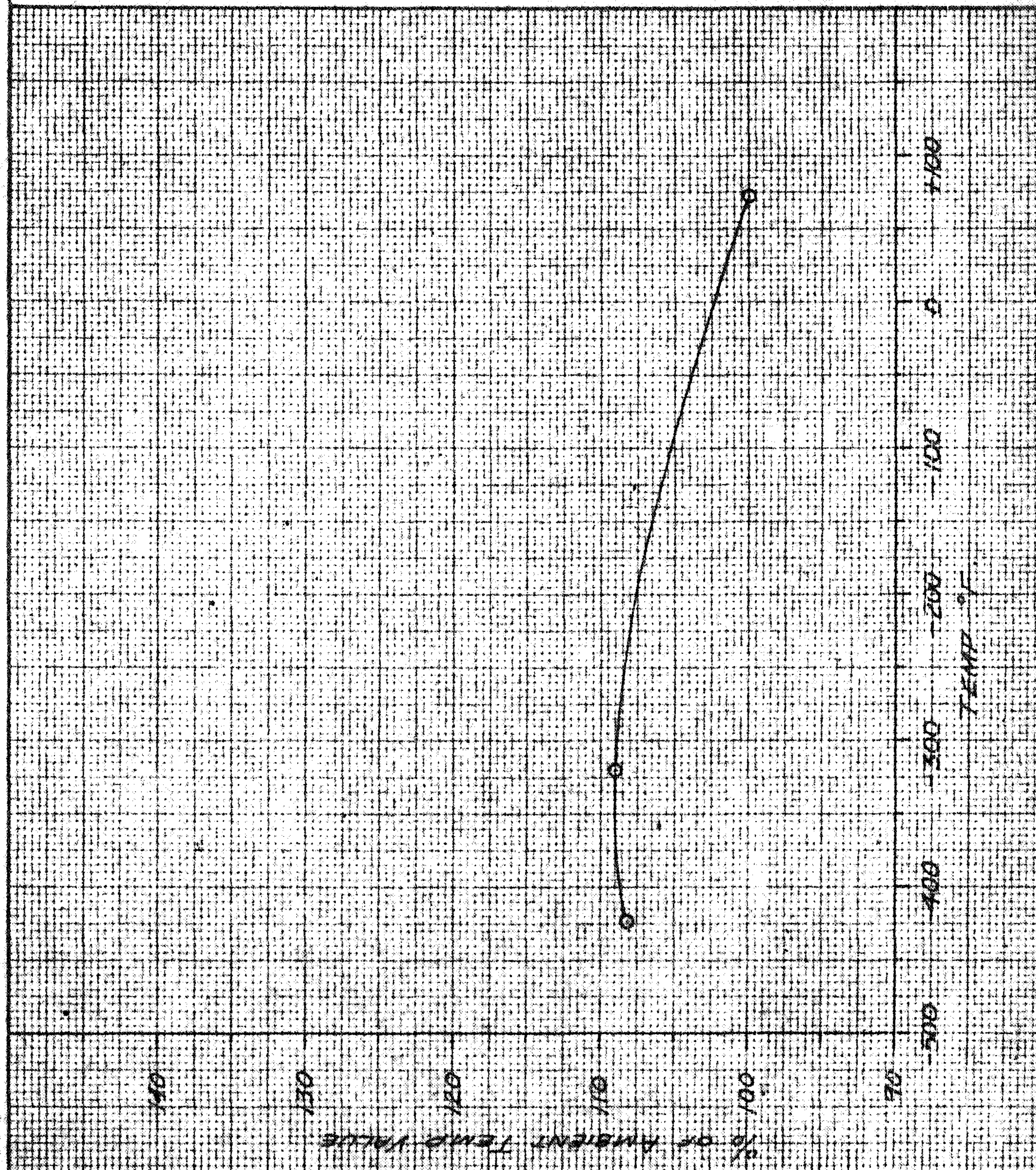
MODULUS OF ELASTICITY AND POISSON'S RATIO

301 XFH Stainless, 0.014 in. Thick,
Heat 7.583, and Coil 1741-A2

SPECIMEN NO.	TEMPERATURE	GRAIN DIRECTION	MODULUS	POISSON'S RATIO
L-1	Ambient	Longitudinal	26.1 x 10^6 psi	-.272
	-320°F		30.0 x 10^6 psi	-.283
	-423°F		28.8 x 10^6 psi	-.297
L-2	Ambient		26.5 x 10^6 psi	-.273
	-320°F		30.0 x 10^6 psi	-.273
	-423°F		30.4 x 10^6 psi	-.295
L-3	Ambient		26.6 x 10^6 psi	-.271
	-320°F		30.3 x 10^6 psi	-.283
	-423°F		30.5 x 10^6 psi	-.291
L-4	Ambient		26.3 x 10^6 psi	-.272
	-320°F		30.2 x 10^6 psi	-.279
	-423°F		31.2 x 10^6 psi	-.307
T-1	Ambient	Transverse	30.1 x 10^6 psi	-.316
	-320°F		33.4 x 10^6 psi	-.315
	-423°F		33.0 x 10^6 psi	-.334
T-2	Ambient		30.1 x 10^6 psi	-.312
	-320°F		34.6 x 10^6 psi	-.320
	-423°F		33.6 x 10^6 psi	-.332
T-3	Ambient		29.8 x 10^6 psi	-.302
	-320°F		33.8 x 10^6 psi	-.313
	-423°F		33.0 x 10^6 psi	-.315
T-4	Ambient		29.8 x 10^6 psi	-.308
	-320°F		33.6 x 10^6 psi	-.303
	-423°F		35.1 x 10^6 psi	-.322

GENERAL DYNAMICS ASTRONAUTICS

FNB-50-12E STRAIN GAGE
% CHANGE OF GAGE FACTOR vs. TEMP.



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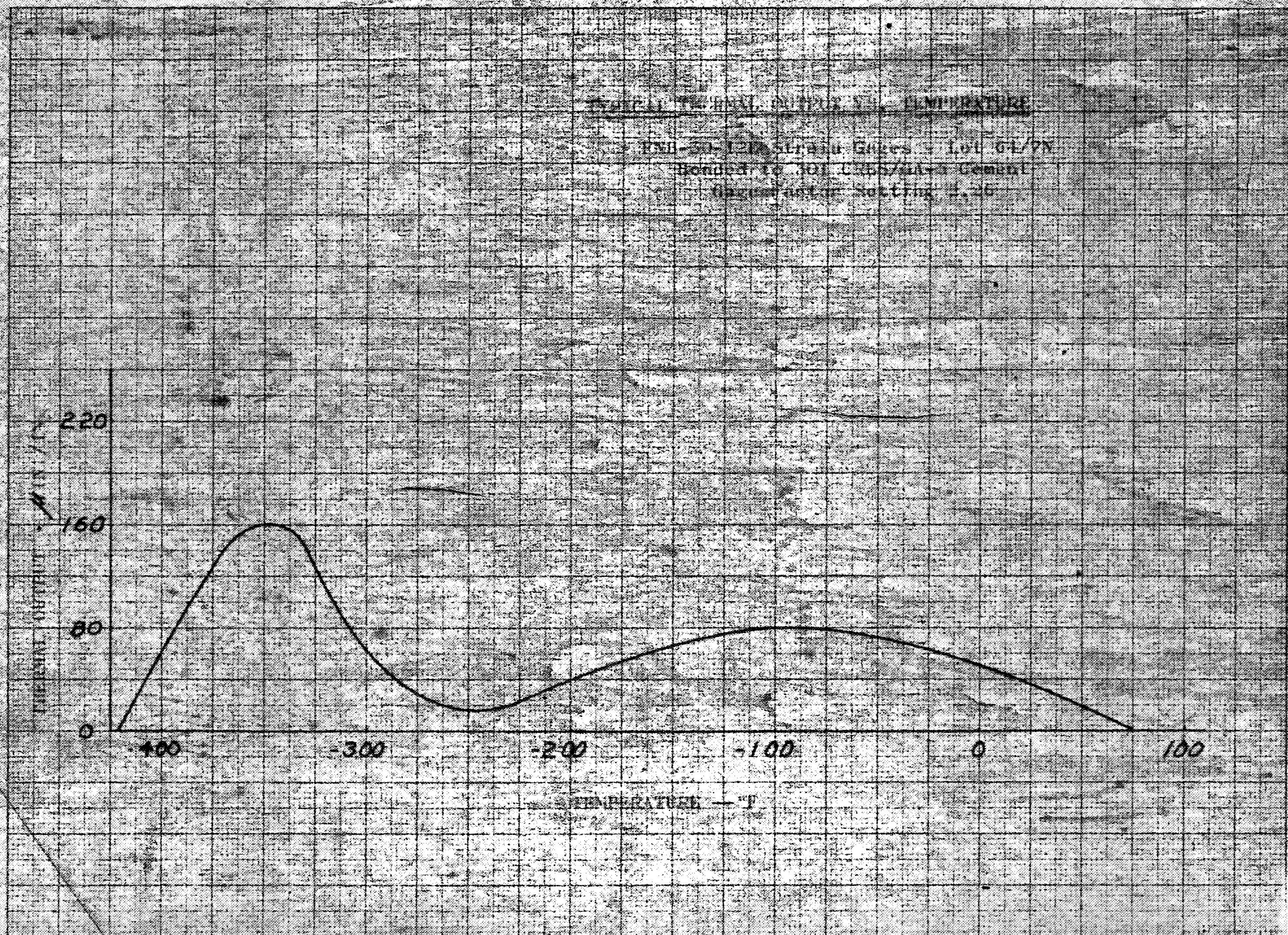

TYPICAL THERMAL OUTPUT VS. TEMPERATURE
Strain Gages - Lot
Bonded to 301
Gage Factor Setting
220
160
80
0
-400
-300
-200
-100
0
100
THERMAL OUTPUT - µIN/IN
TEMPERATURE — °F

APPENDIX D

Evaluation of Characteristics of Type FNB-50-12E Strain Gages Bonded to 301 CRES at Temperatures Between 75°F and -423°F

Pages 68-86

	578-4-M-65-72
DATE	3 June 1965
TO	E. H. Davies, 963-4
FROM	Stress Measurements Group, Electrical Test Laboratory, 578-4
SUBJECT	Evaluation of Characteristics of Type FNB-50-12E Strain Gages Bonded to 301 CRES at Temperatures between 75°F and -423°F
REFERENCE	(A) Sales Order No. 333-1-146 against Contract No. NAS 3-3232
	(B) WAP K0201038, Strain Gage Program TD 126

PURPOSE:

This memo is intended to outline the test procedures and present the results of tests performed on strain gages in support of the AC-6 flight tank strain gage program, TD 126, WO 700-1420-171, WAP K20284802. The contents of this memo will be included in formal report No. 55C-4053.

INTRODUCTION:

Four types of evaluations were made. Three were concerned directly with the characteristics of the type FNB-50-12E strain gage on 301 CRES. The fourth test was performed to determine the resistance change of stranded copper lead wire with temperature. The tests on the strain gages were:

1. Determination of the circuit ballast resistor, R_B, that produces zero bridge output at -423°F referenced to 72°F.

2. Change of strain grid resistance, ΔR_G, and platinum sensor resistance, ΔR_T, with a change in temperature from 72°F to -423°F.

3. Thermal output of the gage over the temperature spectrum from 75°F to -423°F.

The experimental results provided the data to be used in calculating ballast resistor values of the "flight" gages and curves for correction of the "flight" data for temperatures other than -423°F.

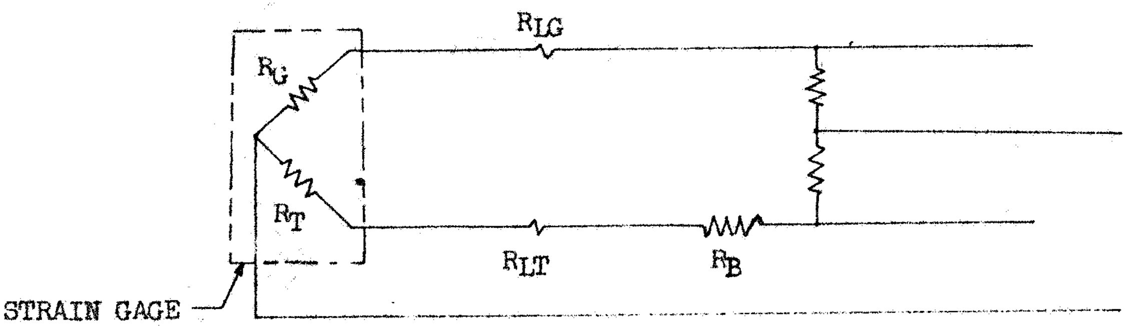
Theoretical Analysis for Calculation of R_B:

The value of the ballast resistor, R_B, to assure a balanced bridge circuit must satisfy the following equation:

$$\frac{R_G + R_{LG}}{\Delta R_G + \Delta R_{LG}} = \frac{R_T + R_{LT} + R_B}{\Delta R_T + \Delta R_{LT}}$$

INTRODUCTION: (Contd)

Where the symbols are defined by the schematic



And the deltas, Δ, represent a small change in the respective elements due to thermal changes.

Solving for R_B and considering the normal case where $R_{LT} = R_{LG}$ we get

$$R_B = \frac{(\Delta R_T + \Delta R_{LT})(R_G + R_{LT})}{\Delta R_G + \Delta R_{LT}} - (R_T + R_{LT})$$

The above formula was the basis for the tests to determine ΔR_T and ΔR_G for the typical strain gages and the effect of temperature changes on lead wire.

TEST SPECIMENS:

The strain gage test specimens were four B-L-H type FNB-50-12E strain gages, lot No. 64/7N, mounted on 301 CRES, 1/2 hard material. The gages were mounted with G A 5 cement in accordance with Procedure Memo ML-563-1-64-44, Rev. B. The stress measurements Strain Gage Installation Request was No. S-1498. The 301 CRES was in the form of a 9-inch long tensile coupon 0.020 inches thick. Two tensile coupons were taped back to back so that the gages faced outward. The gage identification was T-4, T-6, T-8 and T-10.

DETERMINATION OF BALLAST RESISTOR:

The main purpose for determining the value of the ballast resistor, R_B, for each of the four test gages was to give an experimental value to be used in the thermal output test. The second use for the experimental R_B was to verify values of R_B calculated from experimental measurements of ΔR_G and ΔR_T.

Instrumentation and Equipment:

Liquid hydrogen cryostat for specimens.
Liquid hydrogen.

Instrumentation and Equipment: (Contd)

Four strain gage specimens.
Eight General Radio decade resistance type 1432K and 1432N.
B-L-H, Model 525A switch and balance unit.
Two B-L-H strain indicators.

A typical schematic of the strain gage instrumentation layout is presented in Attachment 1. (The thermocouples and associated instrumentation were not used in this test.)

TEST PROCEDURE:

The following procedure of testing was followed for each circuit:

1. Strain indicator gage factor setting at 2.00.

2. Specimens supported by lead wires in cryostat and at room temperature.

3. Set R_B (decade resistance) at low value of predetermined range of 10 ohms. (These values were based on previous testing of the gages.)

4. Set the balance of the switch and balance unit at about center, adjust R_Z (decade resistor) until instrument zero of the strain indicator is observed. Final adjustment may be made by the balance control.

5. Reset R_B to 5 ohms greater than the initial setting, adjust R_Z again to affect a near instrument zero. Record the value of R_Z and the strain indicator reading.

6. Reset R_B to 10 ohms greater than the initial setting, adjust R_Z again to affect a near instrument zero. Record the value of R_Z and the strain indicator reading.

7. Fill the cryostat until the strain gage is covered with LH_2.

8. Set R_B and R_Z in pairs as noted in Steps 4, 5, and 6 above. Record the strain indication for each case.

9. Dump LH_2.

10. Allow the specimen to warm up to room temperature and record the strains again for each R_B and R_Z setting of Steps 4, 5, and 6.

Test Data Reduction:

The strains plotted against R_B (Attachment 2) are the difference of strains recorded at room temperature and at -423°F for the respective R_B. The R_B value on the chart corresponding to no shift of the curve represents the value of the ballast resistor to be used in the circuitry for development of the thermal output vs. temperature curves.

EXPERIMENTAL DETERMINATION OF ΔR_T AND ΔR_G:

ΔR_T and ΔR_G are defined as the change in resistance of a platinum sensor and the active strain element respectively, as the temperature of the gage is changed from room temperature to another constant temperature (-423°F in this case). The typical value of ΔR_T and ΔR_G obtained for the four test gages were used in calculating the value of the ballast resistors for the tank gages.

Instrumentation and Equipment:

Liquid hydrogen cryostat for specimens.
Liquid hydrogen.
Four strain gage specimens.
Five place digital ohmmeter.

TEST PROCEDURE:

1. Support the specimens by lead wires in the cryostat at room temperature.
2. Measure the resistance of the platinum sensor, the strain grid, and both grids in series.
3. Flow LH_2 into the cryostat until specimens are submerged.
4. Measure the resistances as in Step 2 above.
5. Dump LH_2.
6. When specimens have again reached room temperature, repeat Step 2 above.

Test Data Reduction:

The ΔR of the sensor and strain grid is the respective arithmetic differences of the resistance measured at room temperature and at the cryogenic temperature. A constant for the calculation of R_B is the ratio of $\frac{\Delta R}{R}$ averaged for the four test gages, where R is the room temperature resistance of the element corresponding to the test value of ΔR.

The ratios are presented in Attachment 3. Corrections were made in the calculations for lead wire errors and normalizing the initial temperature from 67°F to 72°F.

THERMAL OUTPUT:

The thermal output is the indicated output (or strain) of the strain gage resulting from inherent changes in the grid material and expansion or contracting of the material on which the gage is bonded (unrestrained) caused by temperature changes. This evaluation was done for temperatures from 75°F to -423°F in three parts. Phase I covered the temperature range from 75°F to -314°F; Phase II was a single submergence of the specimens in LN_2 (-320°F), and the third phase included the range from -340°F to -423°F. The composite plot of thermal output vs. temperature provides correction data for test strains measured at any temperature within the plotted range.

Instrumentation and Equipment:

75°F to -314°F Range Test -

Environmental chamber (Missimers Corp. Model FT2-3002C - 1000N_2).

Liquid nitrogen (100 ltr.).

Four strain gage specimens.

Two copper constantan thermocouples.

Potentiometer pyrometer (Thermo-Electric Co. "Mini-Mite," Model 80200).

Strip chart recorder, 6 millivolts, 10-inch chart.

Constant d.c. voltage source, 0 to 10 millivolts, 10 steps.

Two strain indicators, B-L-H, type N.

Switch and balance unit, B-L-H, type 525A.

Eight General Radio decade resistances, types 1432K and 1432N.

A schematic of the instrumentation is found on Attachment 1 (The "Mini-Mite" replaced the 1 mv recorder used on thermocouple 1).

Submergence Test in LN_2 (-320°F) -

Four test specimens.
Five liter dewar.
Liquid nitrogen.
Two-strain indicators.
Four General Radio decade resistances.

-340°F to -423°F Range Test -

Liquid hydrogen cryostat for specimens.
Liquid hydrogen.
Gaseous helium.
Five liter dewar for LN_2.
Liquid nitrogen, 5 liters.

All other equipment was the same as used for the 75°F to -314°F range test except a second recorder was used in place of the "Mini-Mite" and a constant d.c. voltage source of 0 to 1 millivolt (10 steps) replaced the 0 to 10 millivolt source. The recorders were set for 1 millivolt full scale.

TEST PROCEDURE:

75°F to -314°F Range Test:

Temperature control on this test was accomplished with the manual temperature selector and automatic control system. The temperature of the specimens was monitored by use of the two (specimen mounted) thermocouples. A brief step by step procedure of the test sequence follows:

TEST PROCEDURE: (Contd)

75°F to -314°F Range Test: (Contd)

1. Strain indicator gage factor setting at 2.00.

2. Specimens supported by lead wires in chamber.

3. Set R_B to the value ascertained in the "Determination of Ballast Resistor" test.

4. Set the balance of the switch and balance unit at about the center position, adjust R_Z (decade resistor) until a null balance strain is indicated. Final adjustment may be made with the balance knob of the switching unit.

5. Set controller of the chamber temperature to 50°F.

6. Observe when thermocouples mounted on specimens indicate 50°F.

7. Record thermal output of gages (strain).

8. Set controller of chamber temperature for 50°F increments of decreasing temperature and complete the corresponding operations as outlined in Steps 6 and 7.

9. After minimum temperature data is recorded, increase the temperature in 50°F steps, recording thermal output at each level.

10. Repeat Steps 5 through 9.

Submergence in LN_2:

This test was conducted by individually connecting each specimen to a strain indicator along with the decade resistance units for R_B and R_Z to complete the circuit (two gages tested simultaneously).

1. Strain indicator setting at 2.00.

2. Specimen supported by leads at room temperature.

3. Set R_B to the value ascertained in the "Determination of Ballast Resistor" test.

4. Adjust R_Z until a null balance nearest to 11,000 micro-inches per inch is noted on the strain indicator (type N). (Record the reading.)

5. Slowly lower the specimens into LN_2 until the liquid is about 1/4 inch over the gage grids.

6. Record the reading on strain indicator.

7. Remove specimen from LN_2.

8. Record null strain after specimen has warmed up to room temperature.

-340°F to -423°F Range Test:

The temperature was controlled in a cryostat, containing the specimens, by regulating the liquid hydrogen flow and the helium purge. The thermocouples were referenced to the liquid nitrogen temperatures to supress the output band to about 0.75 millivolts for the temperature range of -320°F to -423°F.

The test procedure was as follows:

1. Set up the recorders by adjusting to 1 millivolt full scale by use of the constant voltage source.

2. Suspend the specimens in the cryostat by their lead wires.

3. Set the strain indicator gage factor at 2.00.

4. Set the R_B to the value ascertained in the "Determination of Ballast Resistor" test.

5. Adjust R_Z and the switch and balance unit until a null (instrument zero) is noted on the strain indicator.

6. By adjustment of hydrogen flow obtain a temperature of about -340°F. (The flow was regulated by observing the target temperature on one strip chart recorder.)

7. Record the strain indicator readings while holding the temperature constant.

8. Decrease the specimen temperature in 10 or 20 degree steps to -423°F. Record temperature and strain at each step.

9. Increase the specimen temperature in 10 or 20 degree steps to about -340°F. Record strain and temperature at each step.

10. Allow specimens to warm to room temperature and record strain indications.

Data Reduction:

The thermal output (strain) was plotted against temperature for each strain gage and the respective test. Attachments 4 through 8 illustrate these plots. A composite of the three thermal output tests is presented in Attachment 9.

TEMPERATURE EFFECT ON LEAD WIRE:

The output of the circuit used with the temperature compensating FNB-50-12E strain gage is affected by temperature changes in the lead wires. This effect can lead to false strain readings and incorrect calculations of the ballast resistor (R_B) if leads are not considered. Tests were made to evaluate the change in resistance of wire with temperature.

TEMPERATURE EFFECT ON LEAD WIRE: (Contd)

A series of tests were run at different times on various lead wires. These included the submerging of known lengths of wire in cryogenic fluids and also controlled temperature testing.

The test procedure consisted of measuring the resistance of a known length of wire at room temperature with a digital ohmmeter. Then, when the length of wire was subjected to another temperature, recording the temperature and the measured resistance.

A long length of wire was most desirable to assure the best accuracy (100 feet was the greatest length tested). The best data resulted from tests where the total length of test wire experienced the temperature change, rather than having part of the wire out of the environment and subject to variable temperatures due to heat conduction.

The final data was plotted in the non-dimensional form of ohms per ohms against temperature (Attachment 10).

DISCUSSION OF TEST RESULTS:

There was some discrepancy in the R_B calculated by the ΔR_T, ΔR_G method as compared to the values plotted in Attachment 2. The comparison is tabulated below below.

BALLAST RESISTOR, R_B OHMS			
Strain Gage	Calculated for ΔR_T, ΔR_G	Curve 2 Attachment 2	Discrepancy
T-4	147.2	145.1	+ 2.1
T-6	144.5	141.2	+ 3.3
T-8	145.2	142.9	+ 2.3
T-10	143.6	141.6	+ 2.0

It should be noted that the discrepancies are of the same magnitude and direction with the exception of gage T-6. A faulty decade resistance unit for R_B on gage T-6 caused testing problems.

DISCUSSION OF TEST RESULTS: (Contd)

The results of the thermal output curves were good in general. Data from the two runs shows good repeatability during the chilling part of the cycle. The return to room temperature cycle demonstrated 40 micro-inches/inch or more of thermal hysteresis at 75°F on three gages. In contrast it should be noted that zero shift was realized on at least one gage, T-10.

PREPARED BY D. K. Neff
D. K. Neff

CHECKED BY D. J. Ferris 7-21-65
D. J. Ferris

APPROVED BY R. E. Bailey
R. E. Bailey
Test Lab Group Engineer
Electrical Test Laboratory

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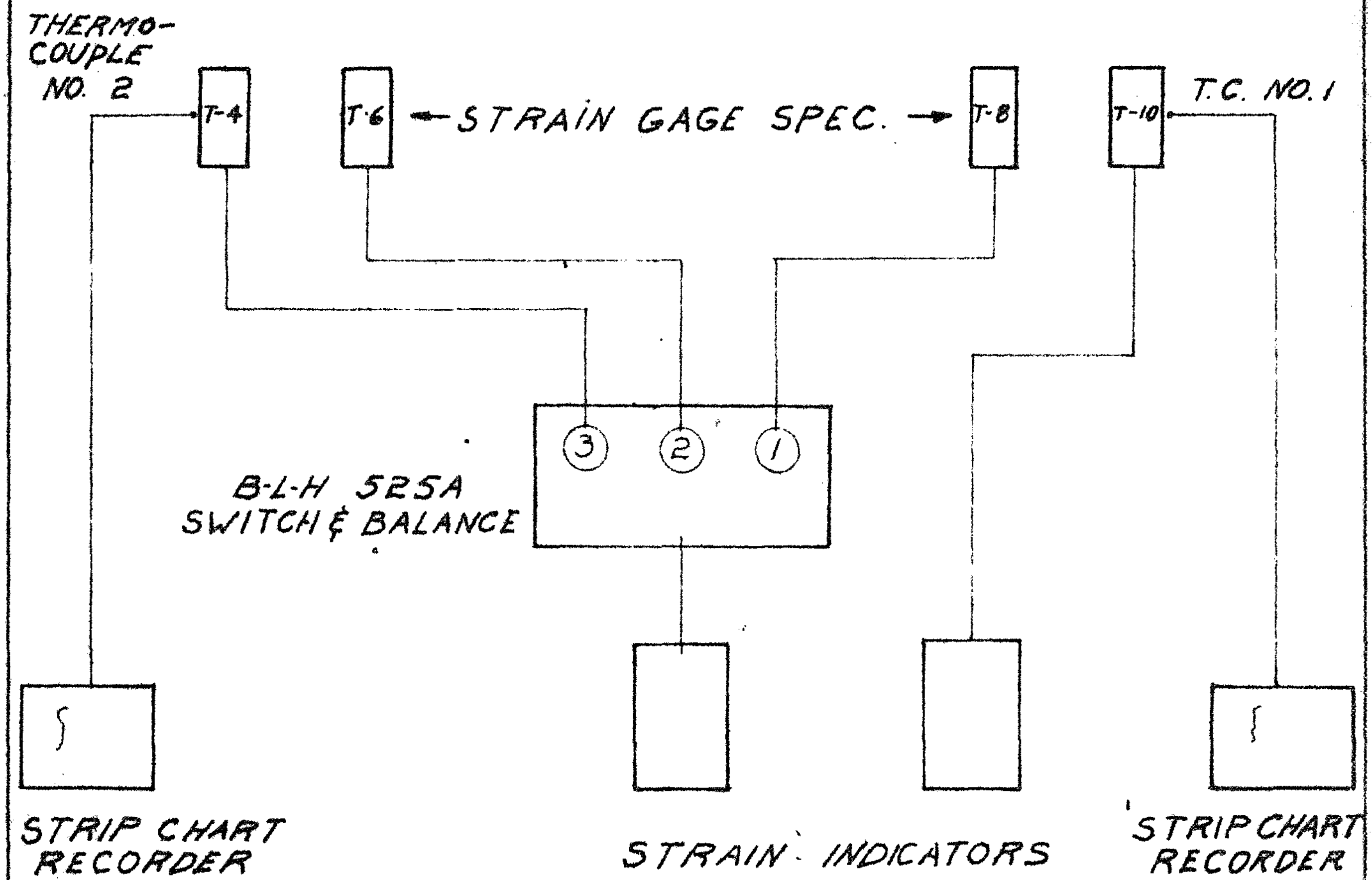
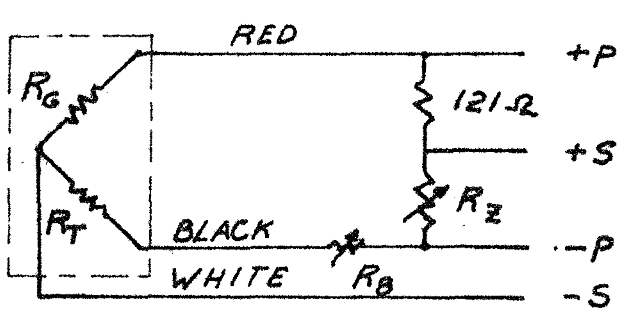
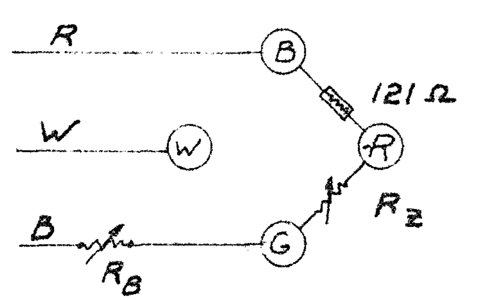
CIRCUIT SCHEMATIC
STRAIN GAGE EVALUATION





TYPICAL CIRCUIT



STRAIN GAGE HOOK-UP TO B-L-H SWITCH & BALANCE

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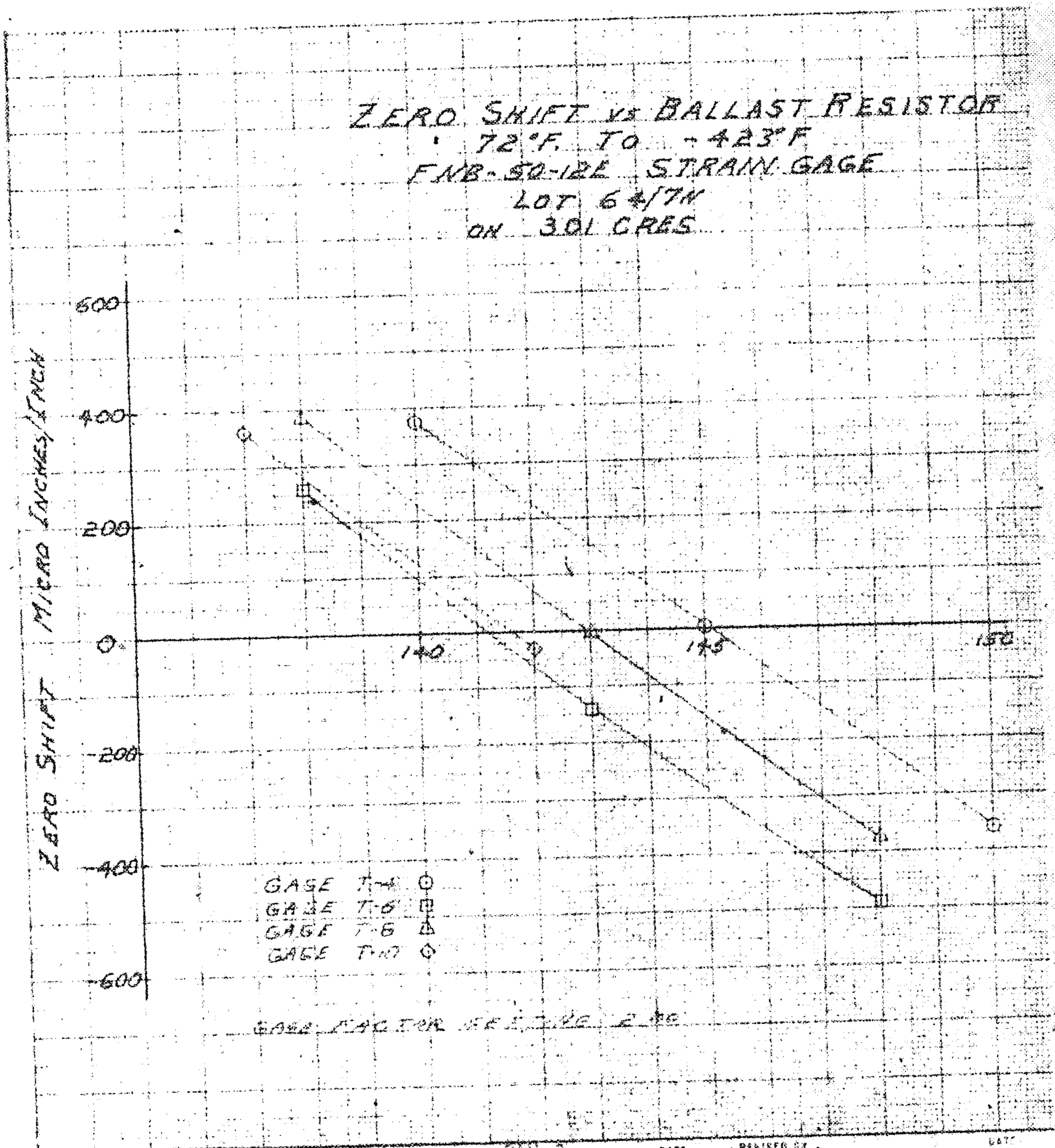

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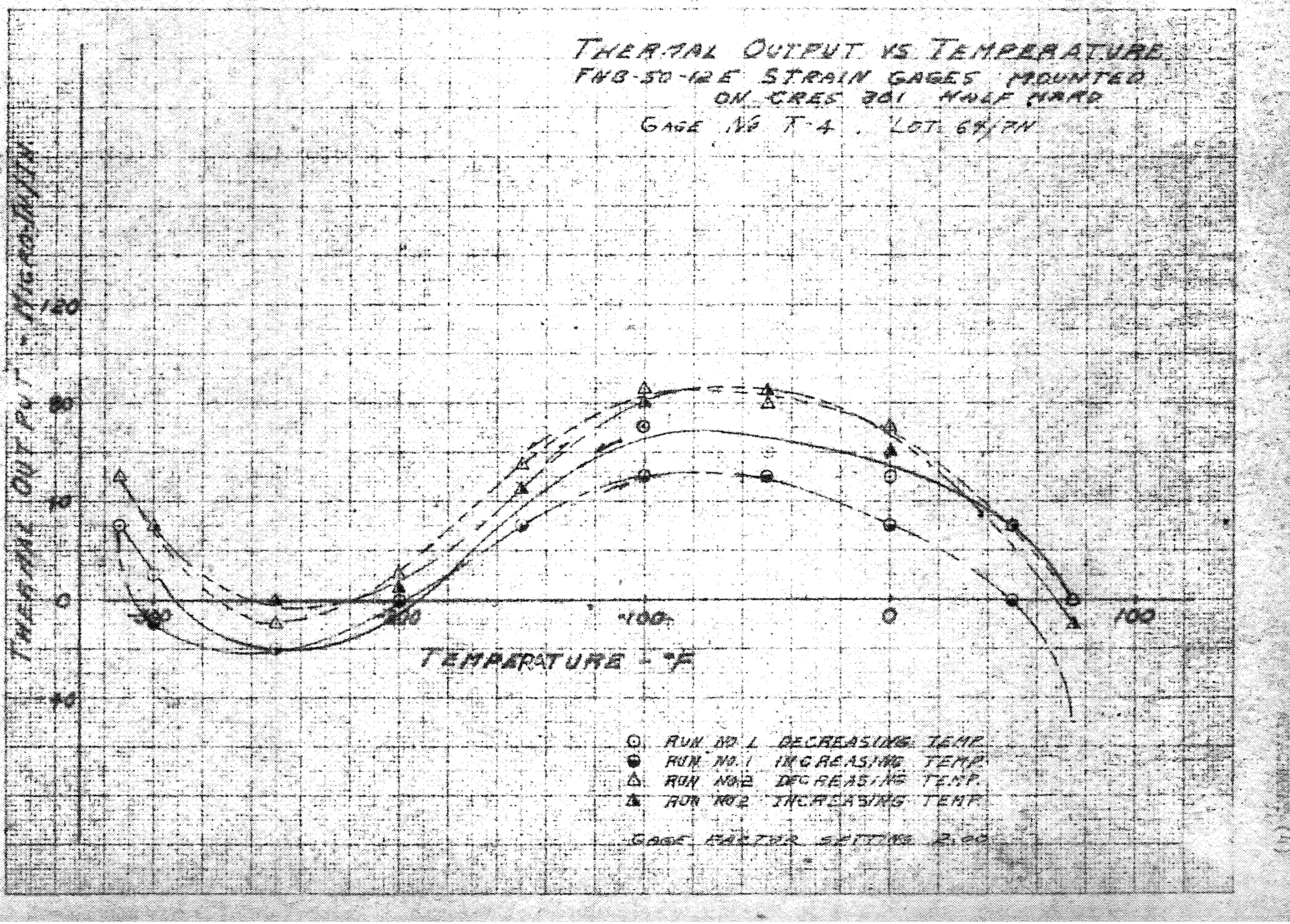
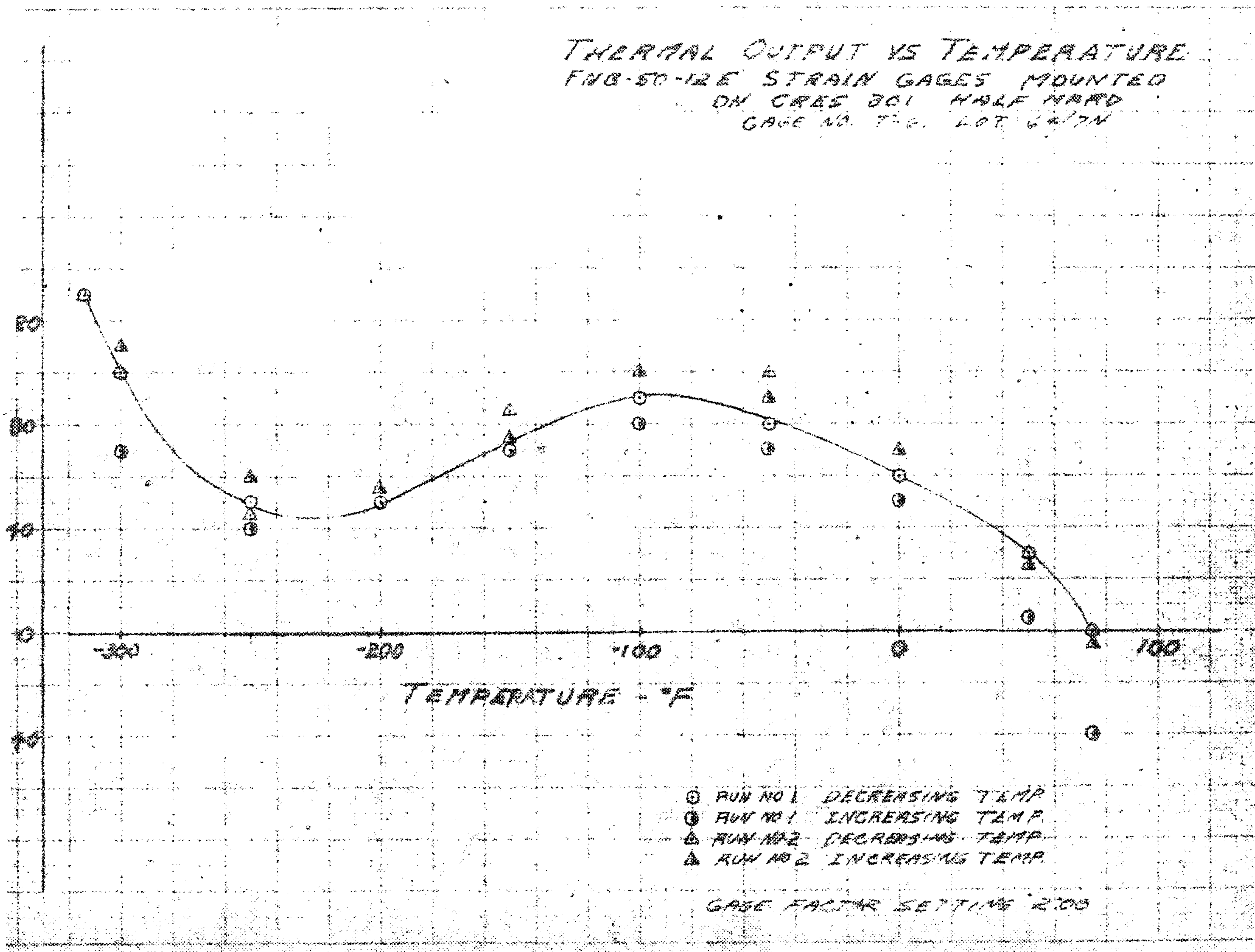
CALCULATION OF RATIOS $\Delta R_G / R_G$ & $\Delta R_T / R_T$ FOR FNB-50-12E GAGES MOUNTED ON 301 CRES - ½ HARD, GAGE LOT 6 & 7.V

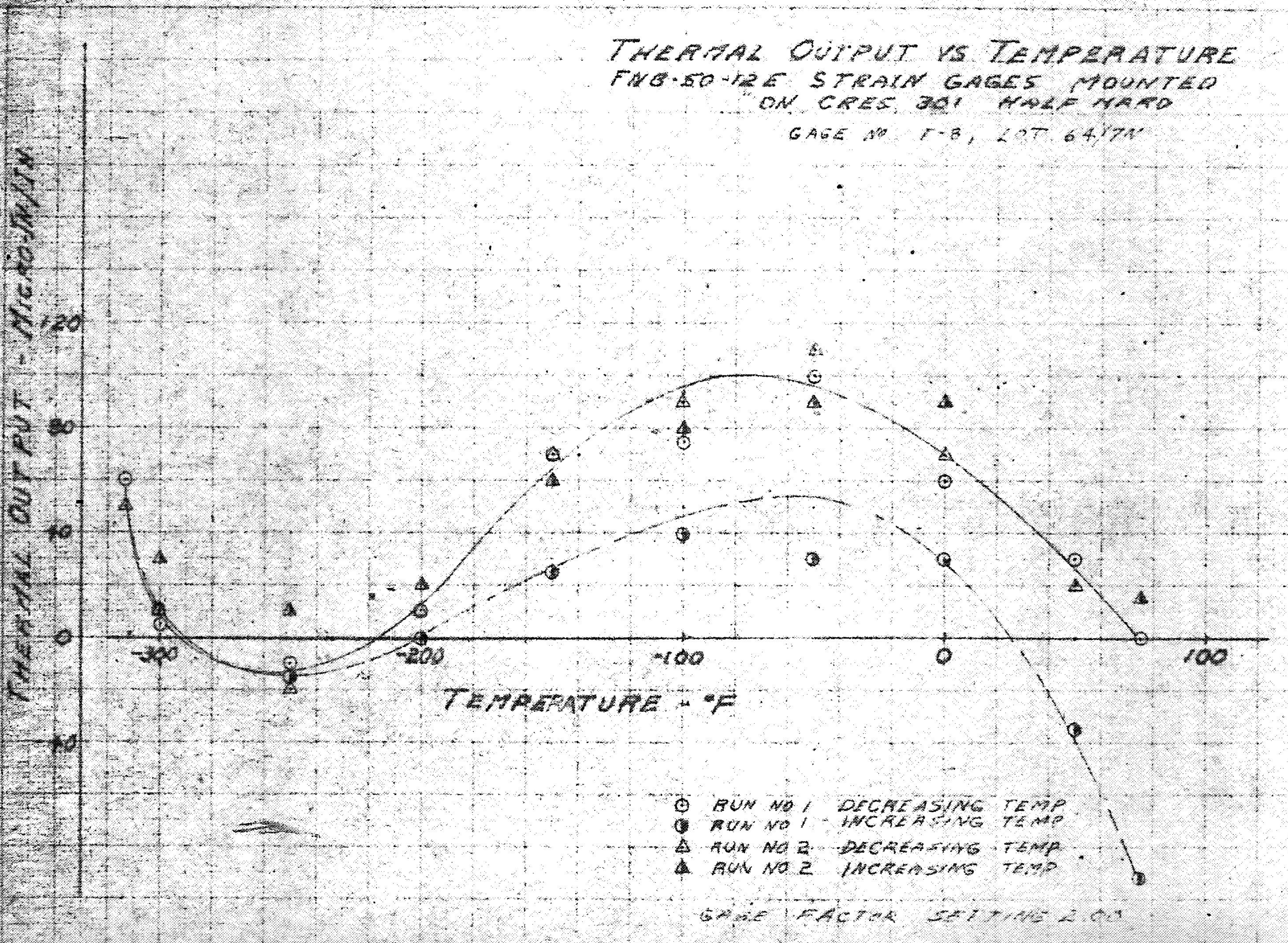
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
STRAIN GAGE	R_N+2R_L @ 67°F	R_N+2R_L @ -423°F	$\Delta R_N + \Delta R_L$	ΔR_L	ΔR_x	Δt	ΔR_G	R_G	$\Delta R_G / R_G$	$\Delta R_G / R_G$ AVG.
T-4	120.22	117.51	-2.71	-0.05	-0.05	0.03	-2.64	119.19	0.02215	
T-6	119.74	117.03	-2.71	-0.05	-0.05	0.03	-2.64	118.67	0.02225	0.02213
T-8	118.49	115.83	-2.66	-0.05	-0.05	0.03	-2.59	117.44	0.02205	
T-10	119.72	117.03	-2.69	-0.05	-0.05	0.03	-2.62	118.66	0.02208	
	R_P+2R_L @ 67°F	R_P+2R_L @ -423°F	$\Delta R_P + \Delta R_L$	ΔR_L	ΔR_x	Δt	ΔR_T	R_T	$\Delta R_T / R_T$	$\Delta R_T / R_T$ AVG.
T-4	4.82	1.43	-3.39	-0.05	-0.05	0.04	-3.33	3.79	0.8786	
T-6	4.80	1.49	-3.31	-0.05	-0.05	0.04	-3.25	3.73	0.8713	0.8790
T-8	4.79	1.42	-3.37	-0.05	-0.05	0.04	-3.31	3.74	0.8850	
T-10	4.75	1.43	-3.32	-0.05	-0.05	0.04	-3.26	3.70	0.8811	

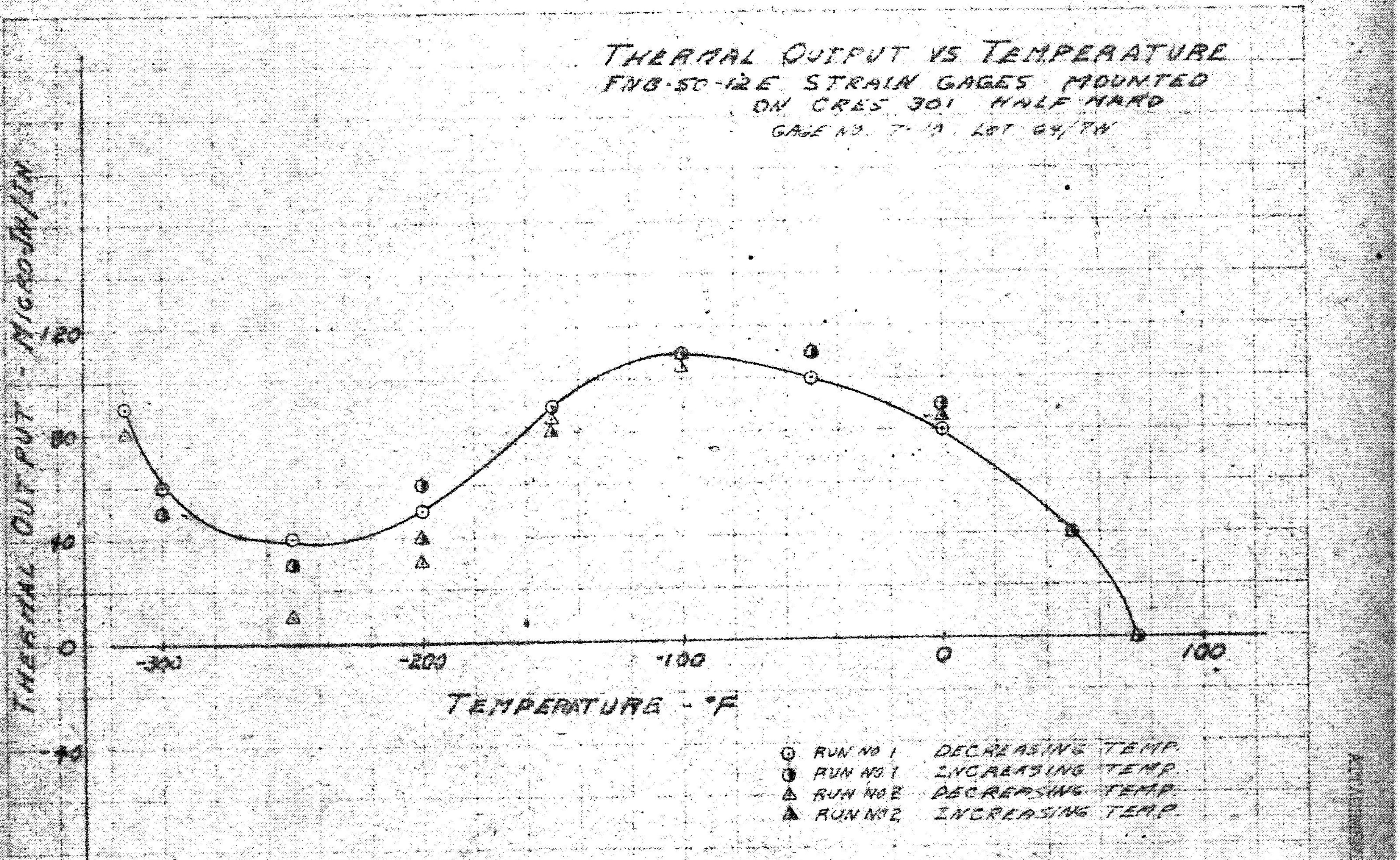
NOTES:
(5) 9" OF LEADS EXPOSED TO LH_2
(6) NICHROME PART OF GAGE BETWEEN R_G & R_T (IN CENTER TAP)
(7) NORMALIZING FROM 67°F TO 72°F
(8) = (4) - ((5) + (6) + (7))

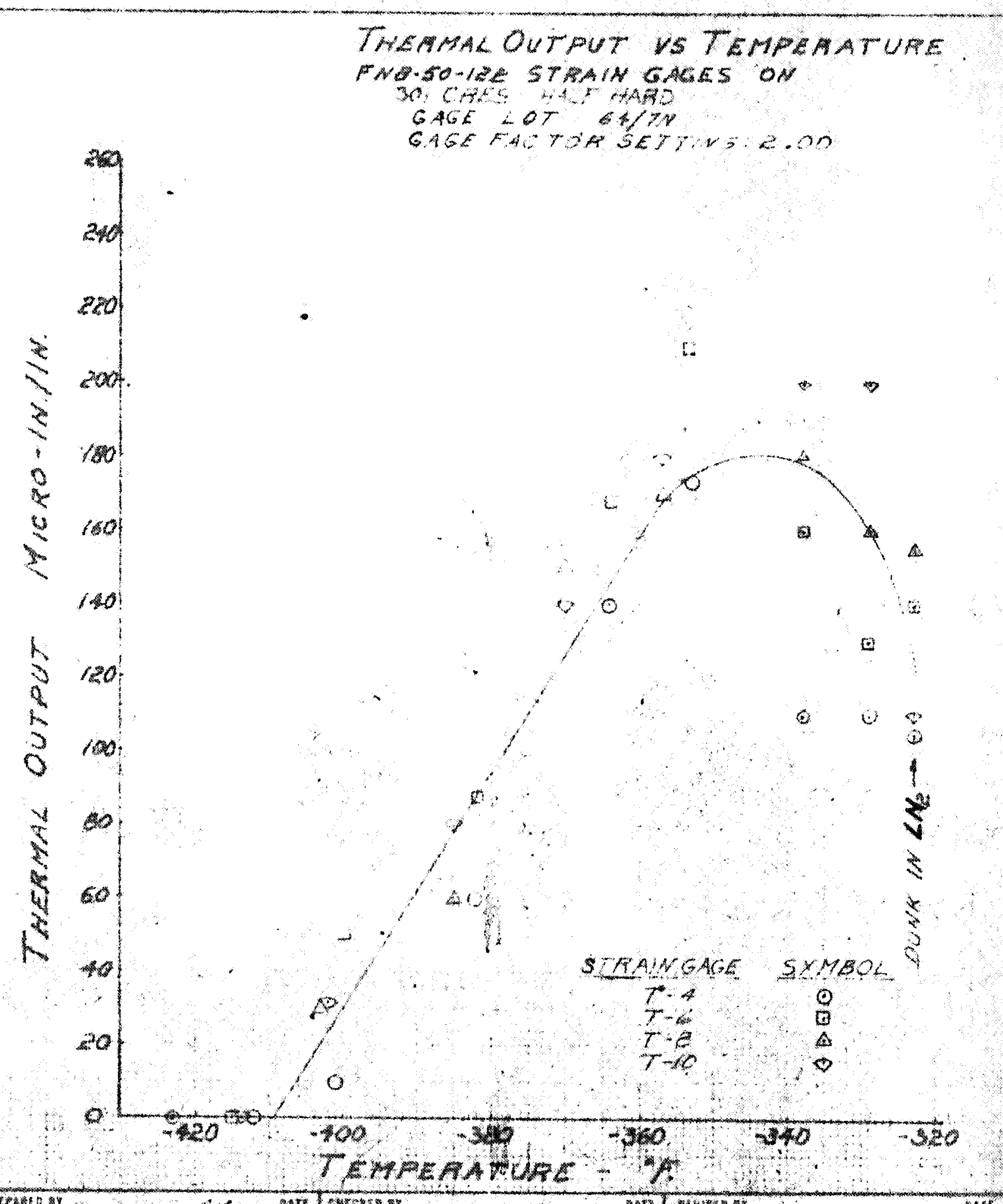
PREPARED BY D.K. NEFF 1/16/65 CHECKED BY


THERMAL OUTPUT VS TEMPERATURE
FNB-50-12E STRAIN GAGES MOUNTED
ON CRES 301 HALF HARD
GAGE NO T-4 , LOT 64/PN
THERMAL OUTPUT - MICRO-IN/IN
120
80
40
0
-40
-300
-200
-100
0
100
TEMPERATURE - °F
RUN NO 1 DECREASING TEMP
RUN NO 1 INCREASING TEMP
RUN NO 2 DECREASING TEMP
RUN NO 2 INCREASING TEMP
GAGE FACTOR SETTING 2.00


THERMAL OUTPUT VS TEMPERATURE
FNB-50-12E STRAIN GAGES MOUNTED
ON CRES 301 HALF HARD
GAGE NO. T-6. LOT 6417N
20
30
40
0
-10
-300
-200
-100
0
100
TEMPERATURE - °F
RUN NO 1 DECREASING TEMP
RUN NO 1 INCREASING TEMP.
RUN NO 2 DECREASING TEMP
RUN NO 2 INCREASING TEMP
GAGE FACTOR SETTING 2.00


THERMAL OUTPUT VS TEMPERATURE
FNB-50-12E STRAIN GAGES MOUNTED
ON CRES 301 HALF HARD
GAGE No. T-8, LOT 64/7N
THERMAL OUTPUT - MICRO-IN/IN
120
80
40
0
-40
-300
-200
-100
0
100
TEMPERATURE - °F
RUN NO 1 DECREASING TEMP
RUN NO 1 INCREASING TEMP
RUN NO 2 DECREASING TEMP
RUN NO 2 INCREASING TEMP
GAGE FACTOR SETTING 2.0


THERMAL OUTPUT VS TEMPERATURE
FNB-50-12E STRAIN GAGES MOUNTED
ON CRES 301 HALF HARD
THERMAL OUTPUT - MICRO-IN/IN
120
80
40
0
-40
-300
-200
-100
0
100
TEMPERATURE - °F
RUN NO 1 DECREASING TEMP.
RUN NO 1 INCREASING TEMP.
RUN NO 2 DECREASING TEMP.
RUN NO 2 INCREASING TEMP.
GAGE FACTOR SETTING 2.00



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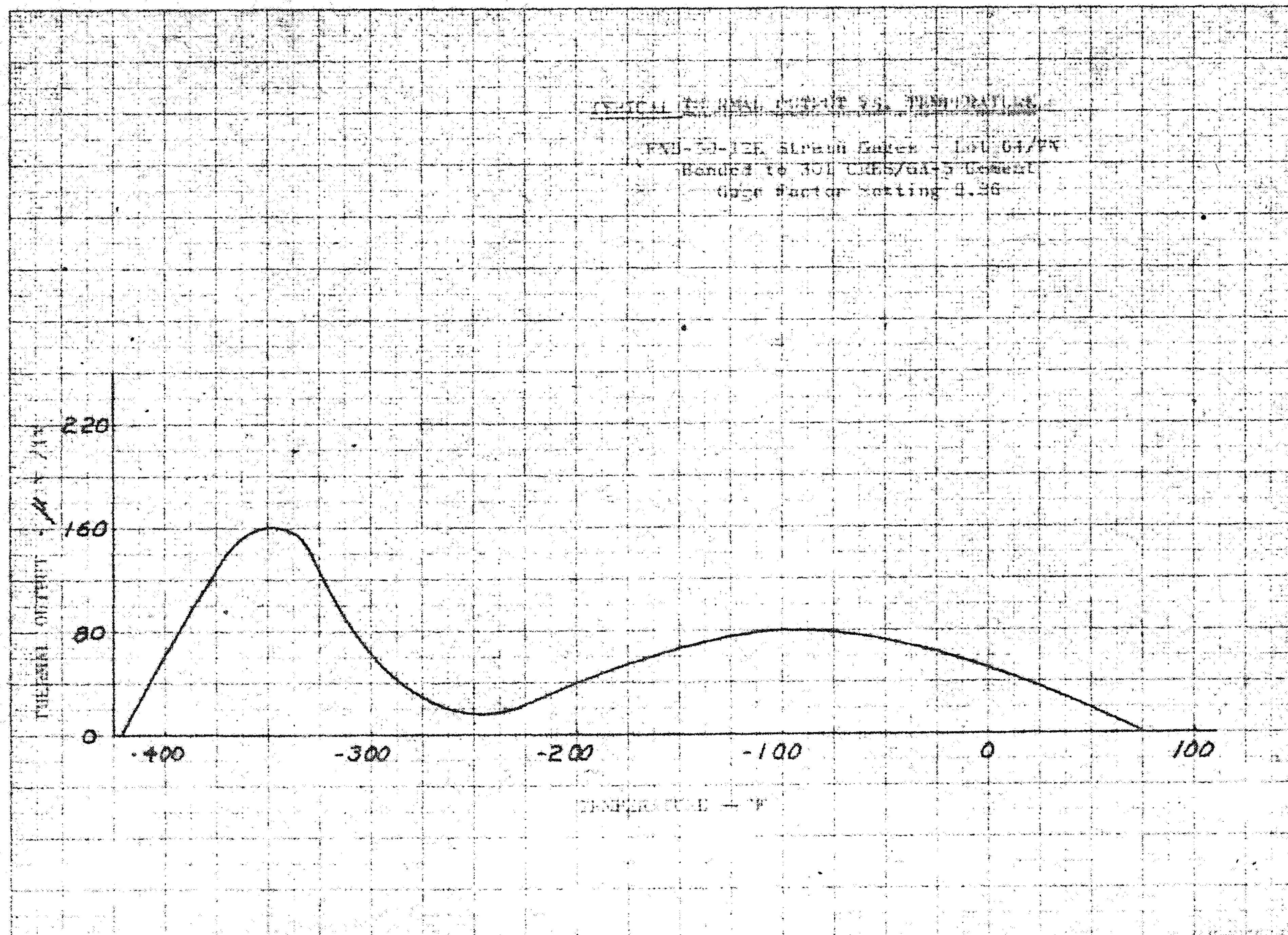
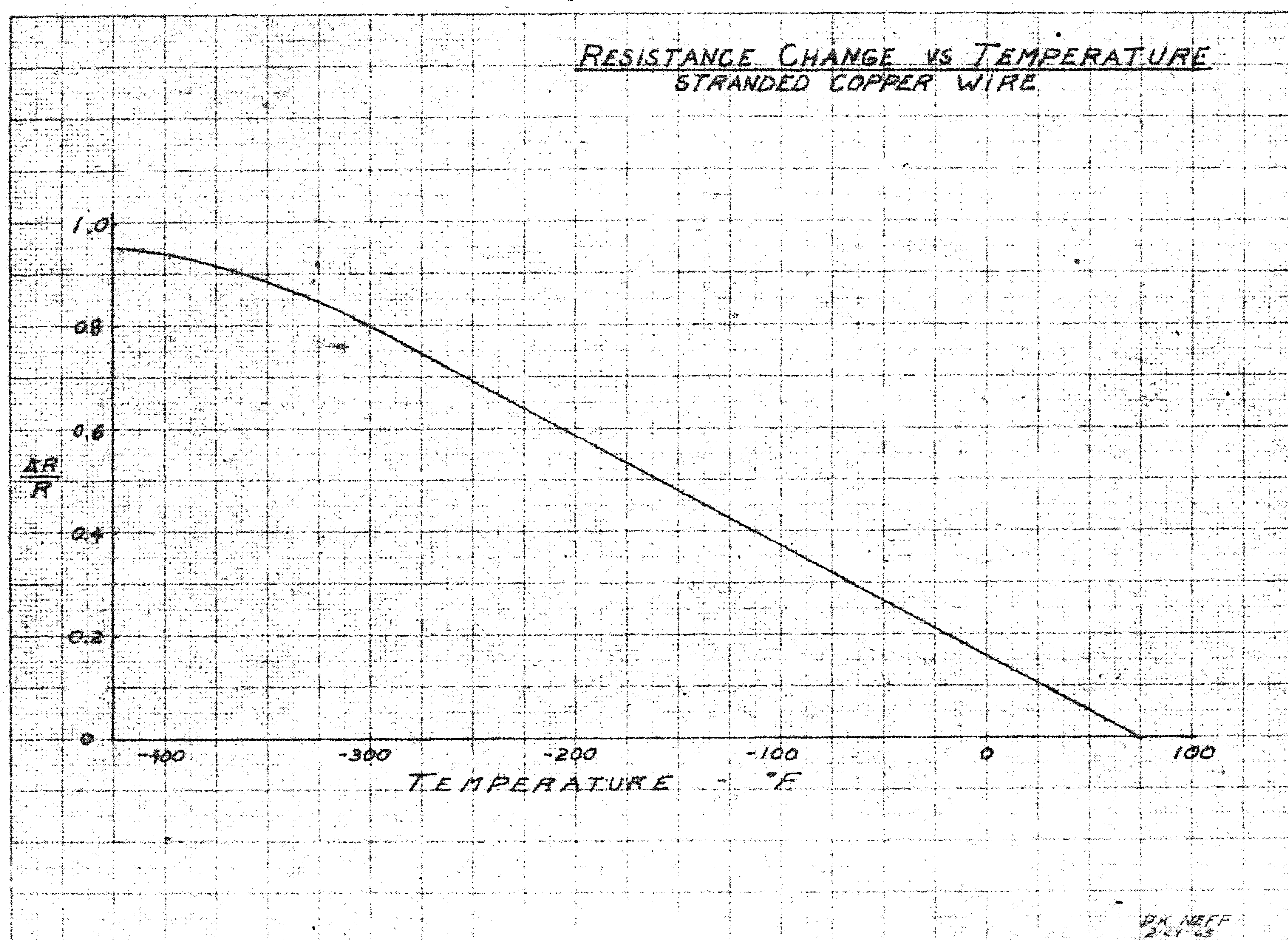

TYPICAL THERMAL OUTPUT VS. TEMPERATURE
Strain Gages
Bonded to
Gage Factor Setting
THERMAL OUTPUT
220
160
80
0
-400
-300
-200
-100
0
100
TEMPERATURE — °F


RESISTANCE CHANGE VS TEMPERATURE
STRANDED COPPER WIRE
1.0
0.8
0.6
0.4
0.2
0
ΔR/R
-400
-300
-200
-100
0
100
TEMPERATURE - °F
D.K. NEFF
2-24-65

APPENDIX E

Procedure for Installation of a Baldwin FNB-15-12E Foil Strain Gage on CRES for Use at Cryogenic Temperatures

Pages 88-93

GENERAL DYNAMICS/ASTRONAUTICS
ML-563-1-64-43
13 April 1964
REVISION A 3-4-65

PROCEDURE FOR INSTALLATION OF A BALDWIN FNT-50-12E FOIL STRAIN GAGE ON CRES FOR USE AT CRYOGENIC TEMPERATURES

1. INTRODUCTION

1.1 Purpose: The purpose is to specify materials and procedural guide for the installation of bakelite backed foil strain gages, such as type FNT-50-12E, on stainless steel.

1.2 Scope: The procedure is for bakelite backed gage installations that will be subjected to cryogenic temperatures.

2. REFERENCES

2.1 Literature

a. Baldwin-Lima-Hamilton Electronics & Instrumentation Division Product Data Report 4321
b. Baldwin-Lima-Hamilton Electronics and Instrumentation Division Technical Data Report 4320-7
c. Budd Instruments Division Catalog BG-2200.
d. NASA Technical Note D-1663.
e. NASA Lewis Research Center in-house report, E-2274.

2.2 Photographs

3. REQUIREMENTS

3.1 Personnel

(A) 3.1.1 One Engineer - Dept. 563-1 - Strain Measurements Section

3.1.2 Engineering Test Support - Dept. 756-0

3.1.2.1 Assistant foreman - Strain Gage Lab.

3.1.2.2 Strain gage technicians

3.2 Equipment

a. S. S. White Type C Industrial Abrasive Unit - "Velvetizer"
b. Portable vacuum cleaner.
c. Triple beam balance.
d. Ungar soldering iron, 22½ watt tip.

3. <u>REQUIREMENTS (Continued)</u>

3.2 <u>Equipment (Continued)</u>

e. Heater blankets, Electrofilm No. 103098 (110V A.C. [illegible] watt)
f. Variac No. 10A (115V A.C., 10 amp)
g. Extension cord
h. Glass mixing r[illegible] for cement.
i. Beaker or glas[illegible] for mixing cement.
j. Eye dropper f[illegible] cement activator.
k. Weldmatic Unitek resistance spot welder (portable)

3.3 Instrumentation:

a. Triplett Multimeter, Type 630-A.
b. Weston Insulation Tester, Model 799, or equivalent.
c. GD/A STL-727 Ohm meter, or equivalent.
d. Portable strain indicator (Baldwin-Lima-Hamilton [illegible])

3.4 Installation Records:

a. Installation log and/or
b. Installation request.

3.5 Materials:

3.5.1 Cleaning materials

a. Chemically pure acetone.
b. Scott 590 Wipers.
c. Butchers detergent - Enthone No 565.
d. Distilled water
e. "Velvetizing" powder - S. S. White "Airbrasive" No. 3.
(A) f. Chemically pure alcohol. (ethyl).
g. Pumice powder, 400 grit paper or B-L-H No. 20164 Fiberglas brush.

3.5.2 Cement

a. GA-5 resin, Budd Co.
b. GA-5 activator, Budd Co.

3.5.3 Strain Gages and Terminal Strips

a. Baldwin-Lima-Hamilton type FAB-50-12S stra[illegible] gages.
b. Budd No. 3 (G-10038) terminal strips.

3.5.4 Wire - 26 gage silver coated copper, shielded, Teflon covered.

3.5.5 Connectors - To be specified on installation request.

3. REQUIREMENTS (Continued)

3.5 Materials (Continued)

3.5.6 Soldering Materials - Ersin Multicore, 18 S.W.G., 3% flux, 60% tin, 40% lead.

3.5.7 Tape

a. Minnesota Mining and Manufacturing cellophane, 3/4" or 1" wide.
b. One inch wide masking tape, Permacel or equivalent.
c. Two inch wide "green" tape, Permacel or equivalent.

3.5.8 Miscellaneous

a. Miscellaneous hand tools.
b. Polyethylene sheet.
c. Sponge rubber pads.
d. Teflon sheet, 0.003" thick.
e. Stainless steel (0.003" thick) strips for lead wire hold down straps.
f. Aluminum protective cover plates.
g. 1/4" sable brush.

4. SAFETY

4.1 Wear Flex-A-Foam dust mask or 3M filter mask and safety glasses during velvetizing operation.

5. PROCEDURE

5.1 Gage Locations

a. Mark approximate location from location drawing or sketch on installation request.
b. Wipe area thoroughly with acetone.
c. Layout strain gage location per drawing or sketch.
d. Mask 4" x 4" area for gage alignment.
e. Wash enclosed area with acetone soaked wiper.
f. Mask 1½" square area (for velvetizing) and mark for gage alignment.
g. Engineer to inspect and initial installation request when OK.
h. Cover with clean polyethylene.

5.2 Surface preparation

a. Set up "velvetizer" with No. 3 powder. Use dry nitrogen at 80 psig.
b. Velvetize sample material before starting on specimen.
c. Velvetize surface to a uniform light grey color. Hold nozzle 2½" to to 3" from surface at approximately 45°. Catch dust with vacuum cleaner. Feather out velvetized surface to masking tape.
d. Blow area off with dry nitrogen.
d. Cover area with clean polyethylene.

5. <u>PROCEDURE (Continued)</u>

5.3 Cleaning - To be done just before cement application.

a. Use detergent wash on velvetized area and rinse with distilled water. Repeat wash and rinse three times. DO NOT WIPE DRY. DO NOT wash over tape on last wash and rinse cycle.
b. Heat lamp may be used to accelerate surface drying. <u>HEAT GUN IS NOT TO BE USED.</u>

5.4 Gage Preparation

a. Roughen gage mounting surface with pumice powder, 400 grit paper, or fiberglass brush.
b. Detergent clean, rinse and dry work area and lay out gages and terminals for tape pickup. Align gage and terminal strips on cellophane tape.
c. Store in protected area until ready for use.
d. Clean gage mounting surface with acetone, just prior to mounting on specimen surface.

5.5 Cement - Mounting Coat

a. Mix 5 gm. of GA-5 resin with 8-10 drops of activator thoroughly in glass container. Allow mixture to sit for 5 minutes minimum before use to minimize air bubbles.
b. Brush a thin layer of cement on installation area.
c. <u>DO NOT USE</u> cement which has been mixed more than 30 minutes.

5.6 Gage Mounting

a. Place gage with terminal strips in position (use alignment marks on masking tape) and secure one end of tape. Be sure that ends of cellophane tape extend beyond cement area. Slide finger from secured end of tape to other end, to mount gage and terminal strips and drive air bubbles and excess cement out.
b. Place Teflon film, heater blanket, sponge rubber pad and metal plate (approximately 1.5" x 1.5") over gage installation and hold tightly in place with green tape and spring steel strip (0.05" x 1" x 8"). Use longer plates for more than two gages. If back to back specimen surfaces are available, clamps may be used.
c. Allow to room temperature cure for 2 hours.
d. Raise temperature slowly to 160° to 180 °F. over two hour period (20°F. per 1/2 hour). Cure at 160° to 180°F. for 4 hours.
e. Allow to cool to ambient temperature. Remove tape and inspect for appearance suitability. Notify engineer of discrepancies.
f. Engineer to inspect and initial installation request if OK.
g. Protect with cover until ready for electrical check.

5. PROCEDURE (Continued)

5.7 Initial Electrical Check

a. Check continuity with Triplett multimeter. Use [illegible] range.
b. Check resistance to ground of gage and terminal strips with Weston insulation tester. (Minimum value 100 megohms).

5.8 Jumper Leads - Terminal Strip to Gage

a. Scrape terminal strip and tin.
b. Solder ribbon leads from gage to terminal strip. (Allow no strain relief loop.)

(A) c. Clean entire area of gage with alcohol using camel's hair brush to remove tape residue.

(A) d. Clean solder joint with alcohol to remove flux (use [illegible] brush).

(A) e. Protect installation until ready for electrical check.

5.9 Electrical Check

a. Measure resistance of each gage with BAL-727 [illegible] and record on installation request.
b. Measure resistance to ground of each gage with Weston insulation tester and record. 100 megohms is acceptable minimum.

5.10 Lead Wire Attachment

a. Secure stripped and tinned lead wire to specimen with tape and spot weld strap over lead wire near gage (minimum of 1.5 inches from terminal strip).
b. Route lead wires to appropriate areas per Installation Request.
c. Scrape cement from terminal strip.
d. Solder leads to terminal strip.

(A) e. Clean solder joint with alcohol to remove flux.

5.11 Electrical Check

a. Check continuity with Triplett multimeter.
b. Check resistance to ground with Weston insulation tester. (100 megohms minimum).

5.12 Connector Attachment (if applicable)

a. Check out individual gage leads for continuity.
b. Solder tinned leads to connector terminals as designated on the installation request.
c. Check continuity and resistance to ground. Engineer to witness and OK wiring.
d. Pot connector per installation request instructions.

5. PROCEDURE (Continued)

5.13 Final Cement Cover

a. Wash with detergent and rinse with distilled water (use brush). Air dry one hour. No wipe.
b. Mix 3 gm. GA-5 resin with 9-10 drops of activator thoroughly and let stand for five minutes.
c. Dab cement over solder joints and etched leads. Let room temperature cure for 2 hours. Apply heat lamp for 6 hours (160° to 180°F.) Bring up to temperature for 2 hours. Cure 4 hours.

5.14 Electrical Check, Final Inspection

a. Measure resistance of each gage with lead wire and connector if applicable and record value. Engineer to witness and initial log.
b. Measure resistance to ground of each circuit and record value. Engineer to witness and initial log.
c. Hook up strain indicator to each circuit and check sensitivity. Engineer to witness and initial log.
d. Secure leads until ready for test.

Prepared by: L. E. Fogleong
L. E. Fogleong, Test Engineer

Checked by: D. J. Morris
D. J. Morris, Senior Test Engineer

Approved by: W. M. Gross
W. M. GROSS, Test Lab Group Engineer

[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	

APPENDIX F

Strain Gage Status Summary for AC-6, Prior to Launch

Pages 95-101

	578-4-M-65-94
DATE	19 August 1965
TO	E. Davies, 963-4
FROM	Stress Measurements, Electrical Test Laboratory, 578-4
SUBJECT	Strain Gage Status Summary for AC-6, Prior to Launch
REFERENCE	(A) Memo 578-4-M-65-38, 23 March 1965, (Status)
	(B) Memo 578-4-M-65-75 9 June 1965 (Checkout)
	(C) .Memo 578-4-M-65-80 16 July 1965 (Panel Loads)

The Stress Measurements Section has been directly involved in all strain gage installations on AC-6. Preflight check-out activity was summarized in Reference (B). Some of the check-out work is specifically covered by WAP authority and some work is in the form of helpful assistance where requested. This memo will discuss the following strain gage installation tasks.

I. Centaur Fuel Tank Strain Gages
II. Insulation Panel Strain Gages
III. Interstage Adapter Strain Gages
IV. Surveyor Payload Latch Clevis Strain Gages
V. Payload Adapter Strain Gages
VI Nose Fairing Split Line Latch Lug Strain Gages

I. Centaur Fuel Tank Strain Gages

All gages were operating properly without rework. The tank strain data from three separate pressure conditions and tanking were examined. The first pressure test was run before insulation panels were installed. Data from this test indicated that channels CA927S and CA928S were identified incorrectly so that hoop strain was less than longitudinal strain at this location. This was corrected before quad tanking. The second pressure test was run after insulation panels were installed and at ambient temperature. The panel effect was not uniform in all channels but was not large enough to alter the data reduction methods which have been set up.

A negative shift of 8% IBW occurred on all channels (except CA933S) between the initial zero adjust 12 July and the time that the telemetry data was recorded at T-81 on 13 July. Later examination (15 July) of the NASA signal conditioning box showed that a negative zero shift occurred when the cover was replaced and the interior package temperature was allowed to rise. NASA was notified and action was initiated to remedy

I. Centaur Fuel Tank Strain Gages (Contd)

the problem. On 8 August, resistors with a higher wattage rating were installed in the strain gage signal conditioning box. Preliminary checks indicated that a more stable operation had been achieved. The strain channels will be adjusted to 2-5% for the AC-6 launch with the hope that no negative shift will develop due to signal conditioning.

No strain channels went further negative due to tanking with liquid hydrogen. Two channels did not change. All other channels moved in the positive direction from 4 to 27%, due to thermal stresses. This is similar to results from the Point Loma testing of test tank EID 55-7545.

The pressure cycle during quad tanking with liquid hydrogen in the tank showed strain values which were less than ambient temperature results as expected. Channel CA943S showed no change due to pressure increase at -420°F. This is unfortunate. The average results for stress determinations using the computer program were as follows:

Comparison of Theoretical and Computed Stresses

from Quad Tanking Data - Tank Skin

	Theoretical	Tanking Results
Hoop stress	22,150 psi	22,528 psi
Longitudinal stress	11,075 psi	11,016 psi

NOTE:

Computer program includes all corrections. Calculations are based on a 5.16 psi change in tank pressure at liquid hydrogen temperature. Data is an average of all strain gages at Station 241 (F. Dittoe, Dept. 587-3).

AC-6 TANK STRAIN GAGE CHECK-OUT SUMMARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14			
Meas. No.	Sta.	Quad	Angle	Gage Dir.	Range $\mu\epsilon$	Strain Change ΔP=5psi 70°F W/O Panels $\mu\epsilon$	Strain Change ΔP=5psi 70°F W/Panels $\mu\epsilon$	Zero NRI 5 psig % IBW	Amb T-81 4.6 psig % IBW	Cold T-10 6.0 psig % IBW	Output Change Due to Sloshing % IBW	Strain Change ΔP=5.7 Cold W/Panels $\mu\epsilon$	Theoretical Strain Change ΔP=5 psi ($\mu\epsilon$)	Point Load Data Strain Change from 5 psi Change in Tank Pressure ($\mu\epsilon$) 70°F W/O Panels	70°F W/Panels	-320°F W/Panels
CA925S	241	I	73	L	0-1500	120	120	0	-7	[illegible]	+15	105	85	70	47	51
CA927S		I,II	90	L	0-1500	120	105	0	-9	[illegible]	+17	90	85	54	54	45
CA928S		I,II	90	H	0-3000	660	630	0	-7	-25	+4	600	610	700	615	572
CA929S		II	107	L	0-1500	90	120	0	-7	9	+18	120	85	7[illegible]	50	57
CA931S		II	135	L	0-1500	10	90	0	-8	-8	[illegible]	60	85	54	125	62
CA933S		III	225	L	0-1500	130	165	0	-5	24	+27	75	85	78	147	50
CA934S		III	225	H	0-3000	600	540	0	-5	[illegible]	+6	570	610	690	586	580
CA935S	241	IV	315	L	0-1500	150	130	0	-8	-8	0	30	85	106	111	65
CA937S	397	I	45	L	0-1500	90	120	0	-8	-7	+13	45	85	103	136	45
CA939S		II	125	L	0-1500	90	-	0	-8	12	20	45	85	90	106	59
CA940S		II	125	H	0-3000	600	-	0	-8	[illegible]	+40	630	610	690	638	645
CA941S		III	225	L	0-1500	90	-	0	-8	15	+23	30	85	111	62	64
CA942S		III	225	H	0-3000	600	-	0	-8	5	+11	630	610	690	627	632
CA943S	397	IV	305	L	0-1500	120	-	0	-8	10	+18	[illegible]	85	86	103	47

NOTES

	Col.	
1.	9.	Zero adjusted with cover removed from signal conditioner
2.	10.	GMT 1139 ambient zero preceding tanking, extended warmup with signal conditioner cover on.
3.	11.	GMT 1258 immediately after LH_2 tank 95% full and before LH_2 vent valve check.
4.	13.	Strain change due to increase in tank pressure from 6.0 psig at 1245 GMT to 11.7 psig at 1301:38 GMT.
5.		IBW stands for telemetry information band width.
6.		$\mu\epsilon$ stands for microinches per inch strain in tank skin.
7.	14.	Includes expected effect of transverse sensitivity of strain gage.

II. Insulation Panel Strain Gages (Panel Load)

All gages operated properly with no rework and the panel loads have been calculated and reported in Reference (C). Initial readings at ETR before panel installation were the same as those taken at Plant 71. Strain readings after panel installation indicated loads as shown in the table below. A pressure test at ambient indicated that gages were all operating and additional load due to pressurizing the tank are shown in the table. Readings were made at T-0 conditions. Temperatures are shown in the table below. Readings were also taken during a pressure cycle of the tanked vehicle. The load at 8.4 psig tanked is shown in the table also. After detanking and warmup, the strain readings returned to near zero, indicating proper operation of the strain gage system. Detailed results will be published in GD/C Report No. 55C-4180.

CENTAUR AC-6 INSULATION PANEL LOADS AND TEMPERATURES

Test Condition	Sta. 280 lbs./in.	Sta. 348 lbs./in.
Stretch fixture (75 lb/in applied).	51.5	48.6
Load induced by installation on vehicle (LH_2 tank pressure 5.0 psig).	53	36
Pressure increased in tank to 8.4 psig, ambient temperature.	59	48
Tanked (tank pressure 5.6 psig, inlet purge pressure 0.13 psi).	82	71
Pressure increased to 12.7 psig with LH_2	89	95
Temperatures		
Ambient before tanking (T-210)		
Inside of tunnel	90°F	90°F
Outside of tunnel	85°F	85°F
Tanked and stabilized (T-0)		
Inside of tunnel	-260°F	-245°F
Outside of tunnel	+30°F	+50°F
Purge Pressure Effect		
Ambient purge pressure effect for 1 psi differential at inlet	35.0 lb/in/psi	37.4 lb/in/psi
Cold purge pressure effect for 1 psi differential at inlet	37.0 lb/in/psi	38.5 lb/in/psi

NOTE:

Purge pressure is reading from CF1047P which is differential pressure between purge inlet and engine compartment pressure.

III. Interstage Adapter Strain Gages

All gages were operating properly with no rework except one. Quick-look data after tanking indicated three longeron DC gages were changing the expected amount but in the wrong direction. This was determined to be a problem in data playback. The strain change due to tanking is shown below. The temperature change was about 10°F. Noise was greater than expected on this data also. The range is about twice as large as it should be. Expected values based on Centaur Stress Group calculations are shown (based on a range of -4000 to +1000). Channel AA926S is questionable since no change due to tanking was noted.

	Telemetry IBW Reading in Percent				
Test Condition	AA926S	AA927S	AA928S	AA929S	Expected
Before tanking T-81	77	80	78	81	80
100% LOX 100% LH_2 T-0	77	77	75	76	76

IV. Surveyor Payload Latch Clevis Strain Gages

All gages operated properly without rework. Preload values are shown below. No problems were encountered with the pretension operation. Strain gage bridge output was read using SR-4 Strain Indicator S/N 900666. The clevis nut torque was increased to give a bolt load of 5000 lbs. and then reduced to give a bolt load of 2300 lbs.

PAYLOAD LATCH CLEVIS CHECK-OUT SUMMARY

MLX No.	Measurement No.	Plt. 71 Zero Sept. '64	ETR Zero Aug. '65	ETR Preloaded	Output Change	Load (lbs)
631	CA144S	14420	14680	16298	1618	2280
634	CA145S	12905	12785	14392	1607	2300
633	CA146S	13040	12921	14482	1561	2300

V. Payload Adapter Strain Gages

All gages operated properly without rework. The check-out readings on the bridge output changes between (1) payload off, and (2) payload on and no latch torque. The difference in readings were larger than previous calibration readings. The readings did verify proper signal response to load as connected to SR-4 indicator, S/N 900666. The calibration readings refer to a load calibration performed at Plt. 71 in September 1964. This calibration was made with the payload adapter bolted to a short section of cylinderical adapter which in turn was bolted to a large steel plate. The payload was secured to the adapter by torquing the payload latches to the proper values. The calibration loads were then applied. The calibration output was measured for the change from 2100 lbs. to 7100 lbs. (with the payload latch tension present) using SR-4 Strain Indicator, S/N 392010. The check-out output was measured for the change from 0 lbs. to 2100 lbs. without the influence of latch tension. No calibration data exists which is directly comparable to the check-out values. Based on the available information, it is recommended that the calibration information be used for flight data evaluation.

AC-6 PAYLOAD ADAPTER STRAIN GAGE CHECK-OUT DATA

Measurement No.	Bridge output due to applied load of 2100 lb. on clamped adapter (Microinches/in.)	Bridge output due to placing AC-6 payload on unclamped adapter (Microinches/in.)
CA491SA	130	225
CA491SB	100	215
CA491SC	85	200
CA492SA	125	145
CA492SB	110	133
CA492SC	95	115
CA493SA	120	230
CA493SB	80	219
CA493SC	70	199

VI. Nose Fairing Split Line Latch Lug Strain Gages

All gages operated properly without rework. The lug loads were read during Nose Fairing assembly before quad tanking and before launch using SR-4 Strain Indicator, S/N 900666. The prelaunch readings are shown below. No problems were encountered. Loads were read (1) after each pair of latches were torqued and the fixture had been removed, (2) after all latches had been torqued in the clean area, and (3) on the missile.

S/N	Location	Quad	Condition 1 Load (Lbs)	Condition 2 Load (Lbs)	Condition 3 Load (Lbs)
48	Conical Section Bottom	III, IV	1330	1250	1200
45	Conical Section Center	III, IV	1660	1960	1790
42	Conical Section Top	III, IV	1910	1910	1660
46	Conical Section Bottom	I, II	1530	1430	1250
41	Conical Section Center	I, II	1350	-	1370
44	Conical Section Top	I, II	1860	-	1560
43	Barrel Section	III, IV	1300	-	1300
47	Barrel Section	I, II	1450	-	1450

PREPARED BY D. J. Ferris 8-24-5
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APPENDIX G

AC-6 Flight Strain Gage Data Evaluation

Pages 103-116

AC-6 FLIGHT STRAIN GAGE

PROGRAM TD 126

POST FLIGHT DATA EVALUATION

NAS3-3232

GENERAL DYNAMICS
Convair Division

C
O
P
Y

DATE 25 February 1966

TO A. C. Ward

FROM P. B. Bunch

SUBJECT AC-6 Flight Strain Gage Data Evaluation

Recommended Action:

Information

Problem:

None

Discussion:

The attached report summarizes results of the data evaluation for the AC-6 flight strain gage program. This program was authorized under NASA Technical Directive 126.

Prepared by ______________________
/s/ P. B. Bunch

cc: D. J. Ferris
W. T. Su
J. R. Cannau
J. H. Jenness
File

INTRODUCTION

This report summarizes the results of an evaluation of strain gage data obtained from the AC-6 flight. This task was authorized by Technical Directive 126, NASA Contract NAS3-3232.

The intent of this program was twofold; 1) measure actual stress level changes experienced by the Centaur fuel tank during flight, and 2) calculate flight loads using the stress data.

Figure 2, appendix, illustrates sign convention used in denoting flight loads experienced by the Atlas-Centaur vehicle.

Stress levels were calculated using telemetered strain data; however, stress levels and moments calculated did not correlate with expected loading indicated by another measured data. Erratic data obtained was the result of unpredictable degree of insulation panel restraint each area provides to the strain gages.

BACKGROUND

Strain gages (Type FNB050-12E) were bonded to the outer surface of the Centaur liquid hydrogen tank at six locations for Station 241 and four locations for Station 397. (See Figure 1 Appendix). Axial strain was measured at each location while hoop strain was measured at only two locations per station level. Ideally, both hoop and axial strain would be measured at each location. However, due to the limited channel availability, hoop strain measurements were limited as stated above. This less than ideal situation does not compromise the results to any great extent as the hoop strain theoretically should not vary significantly around the tank and is not affected by external loading.

The telemetered strain data was converted to stress using the IBM 7094 DCS Digital Computer Program 3833. Complete results, both tabulated and plotted, are presented in AS-D-991. Equations used to determine moments are also found in this reference. To further enhance the accuracy of the results, engineering constants, modulus of elasticity (E) and poissons ratio (μ) were experimentally determined for tank skin samples from the same heat and coil as the flight vehicle. (Reference 2)

RESULTS

Flight loads occurring at the time of maximum aerodynamic loading (mag q) were of particular interest. Since this is the time of maximum bending moments, vehicle fuel tank skins are critical. Other flight times of interest were BECO (maximum axial load) and insulation panel jettison. A summary of the results of this analysis for these events is presented herein.

A. BENDING MOMENT AT MAX q

Axial stress at three circumferential locations was used to compute bending moments at Station 241 and Station 397 which correspond to the forward and aft end of the Centaur fuel tank.

Bending moments computed in this manner (presented in Reference 1) using flight data appeared to be unrealistically large when compared with the angle of attack excursions and interstage adapter bending moment data.

Evaluation of Quad-tanking strain data pointed out that bending moments were indicated during pressurization tests. Definite linearity with pressure increase precluded the existence of an actual applied moment of this magnitude. This is clearly indicated in Figure 5 and 6 of the appendix.

Since the moment calculations were based on stress differences along the tank circumference, any variation in the pressure stress field would result in the indication of an applied bending moment. Furthermore, due to the magnitude of the tank section modulus (I/C), small stress differences result in significant bending moments.

An attempt was made to compute a correction factor, utilizing Quad-tanking data, for the strain gage to strain gage pressure stress variation. However, the resulting corrected flight bending moments were further increased. It was concluded that the correction factor based

A. BENDING MOMENT AT MAX q (Cont'd)

on static conditions (Quad-tanking) was not valid for flight. This could be caused by insulation panel shifting on the tank or other effects causing a change in insulation panel restraint.

Evaluation of the effects of the insulation panels on the tank stress field presents the greatest problem in computing flight bending moments. Previous test programs (Reference 3) have indicated the panels definitely tend to restrain the tank skins resulting in increased axial tension stress. This induced stress does vary around the tank and introduces unaccountable errors in the moment calculations. As a result of this analysis the derived flight bending moments are not considered valid.

B. BOOSTER ENGINE CUTOFF(BECO) T+142 SEC.

Booster engine cutoff results in a rapid decrease in longitudinal acceleration of the vehicle with a corresponding increase in tank skin stress. The table below shows the excellent correlation between theoretical and measured stress changes at BECO.

STA	MEASURED $\Delta\sigma_1$, PSI	CALCULATED $\Delta\sigma_1$ PSI
241	4800	4800
397	6400	5200

C. INSULATION PANEL JETTISON T+171.8

The stress perturbations occurring at panel jettison clearly support the statement made in regards to predictability of axial restraint of the panels on the tank. However, the hoop restraint due to initial panel pretension at installation is in good agreement with the design values. The following table summarizes the stress changes at each gage location:

C. INSULATION PANEL JETTISON T 171.8 (Cont'd)

LOCATION	$\Delta\sigma_1$, (% LONGITUDINAL)	$\Delta\sigma_2$, (% HOOP)
1	-10	-
2	-6	+5
3	-9	-
4	+6	-
5	-4	+6
6	+3	-
7	-4	-
8	-1	+8
9	-7	+5

(+ Indicates increase in stress)

CONCLUSIONS:

1. Due to the errors introduced by the Insulation Panel effects on the stress distribution around the fuel tank, bending moments cannot be calculated with any degree of accuracy.

2. This program successfully demonstrated the feasibility of using strain gages in the complex environment experienced by missiles and space vehicles.

3. The stress data obtained from this program supported the analytical methods used to establish launch restrictions in regards to pressurization requirements.

4. Included in this report are plots of significant data supporting this analysis. This information can be found in the attached appendix.

RECOMMENDATIONS

This technique used in the evaluation of external loads should not be used on complex structures such as the tank-insulation panel combination. However, application to simpler structures should yield satisfactory results.

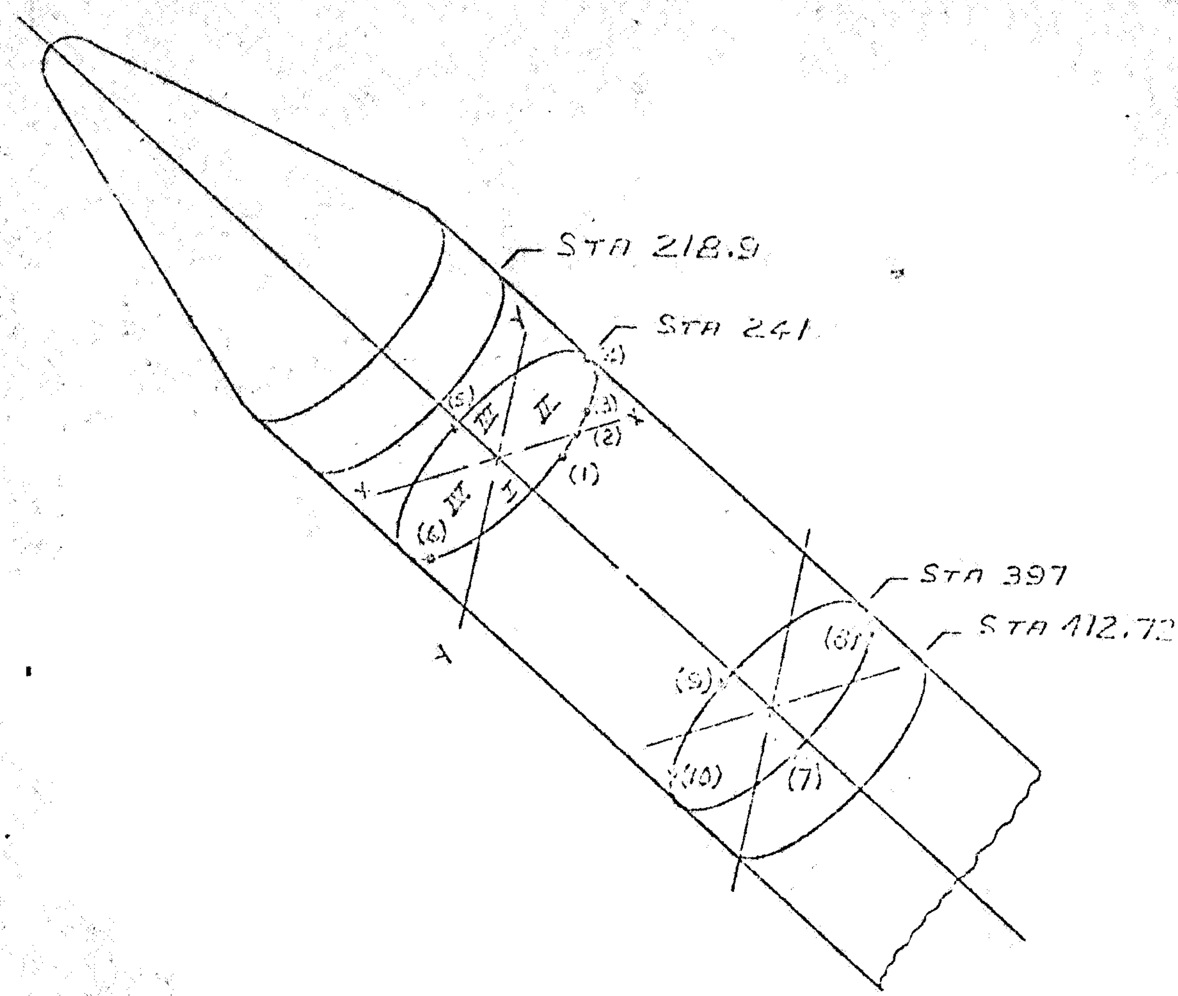
REFERENCES

1. AS-D-991, "Analysis of AC-6 Flight Strain Gage Data," dated 8 September 1965.

2. Memo 578-4-M-65-82, "Results of Material Property Tests and FNB-50-12E Strain Gage Evaluation," dated 22 June 1965.

3. Test Report 55B3309, "AC-6 Axial Load and Bending Moment Test Results."

AC-6 STRAIN GAGE LOCATIONS



MEASUREMENT I.D.

LOCATION	AXIAL	HOOP
1	CA925S	—
2	CA927S	CA928S
3	CA929S	—
4	CA931S	—
5	CA933S	CA934S
6	CA935S	—
7	CA937S	—
8	CA939S	CA940S
9	CA941S	CA942S
10	CA943S	—

EXTERNAL FLIGHT LOADS

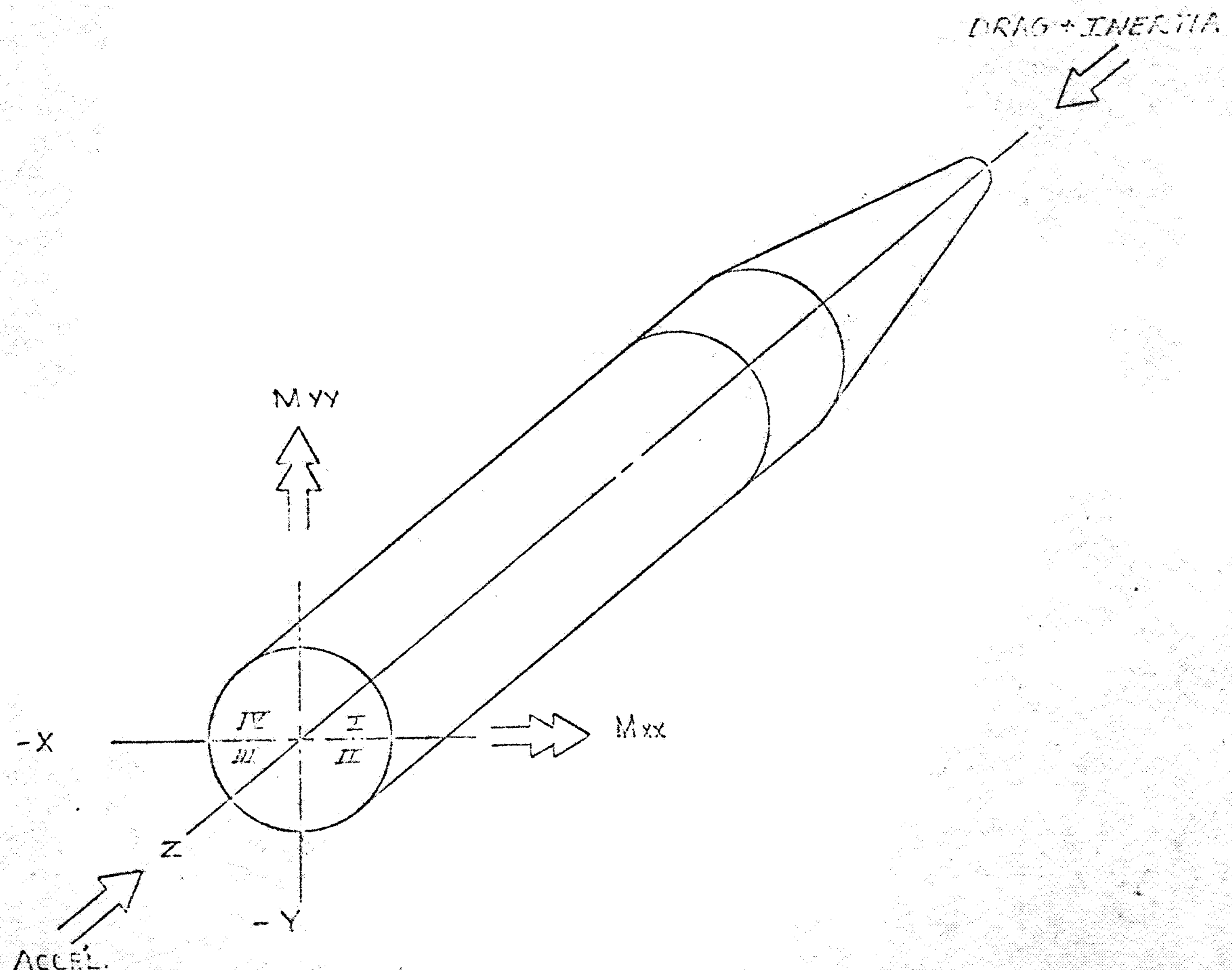
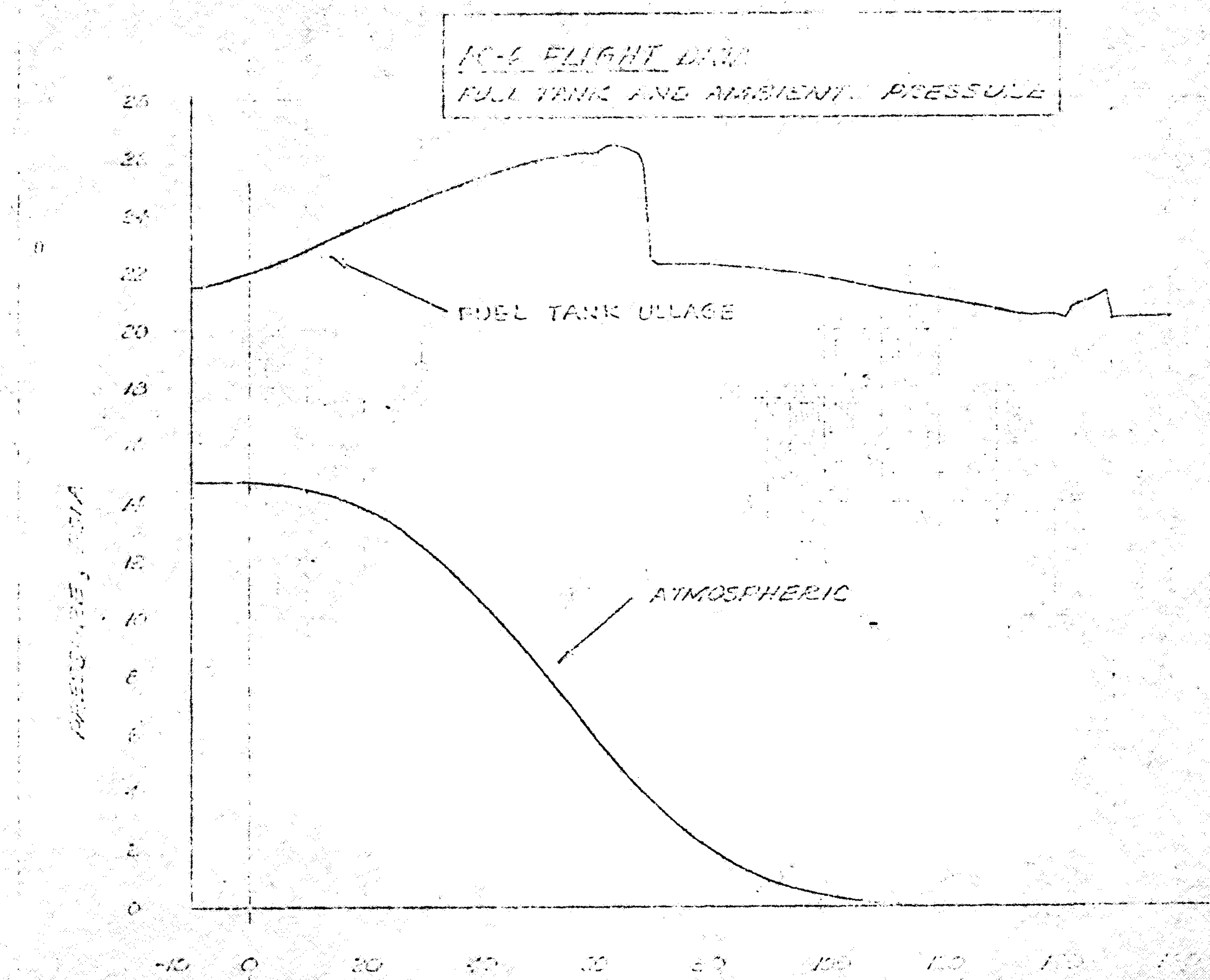
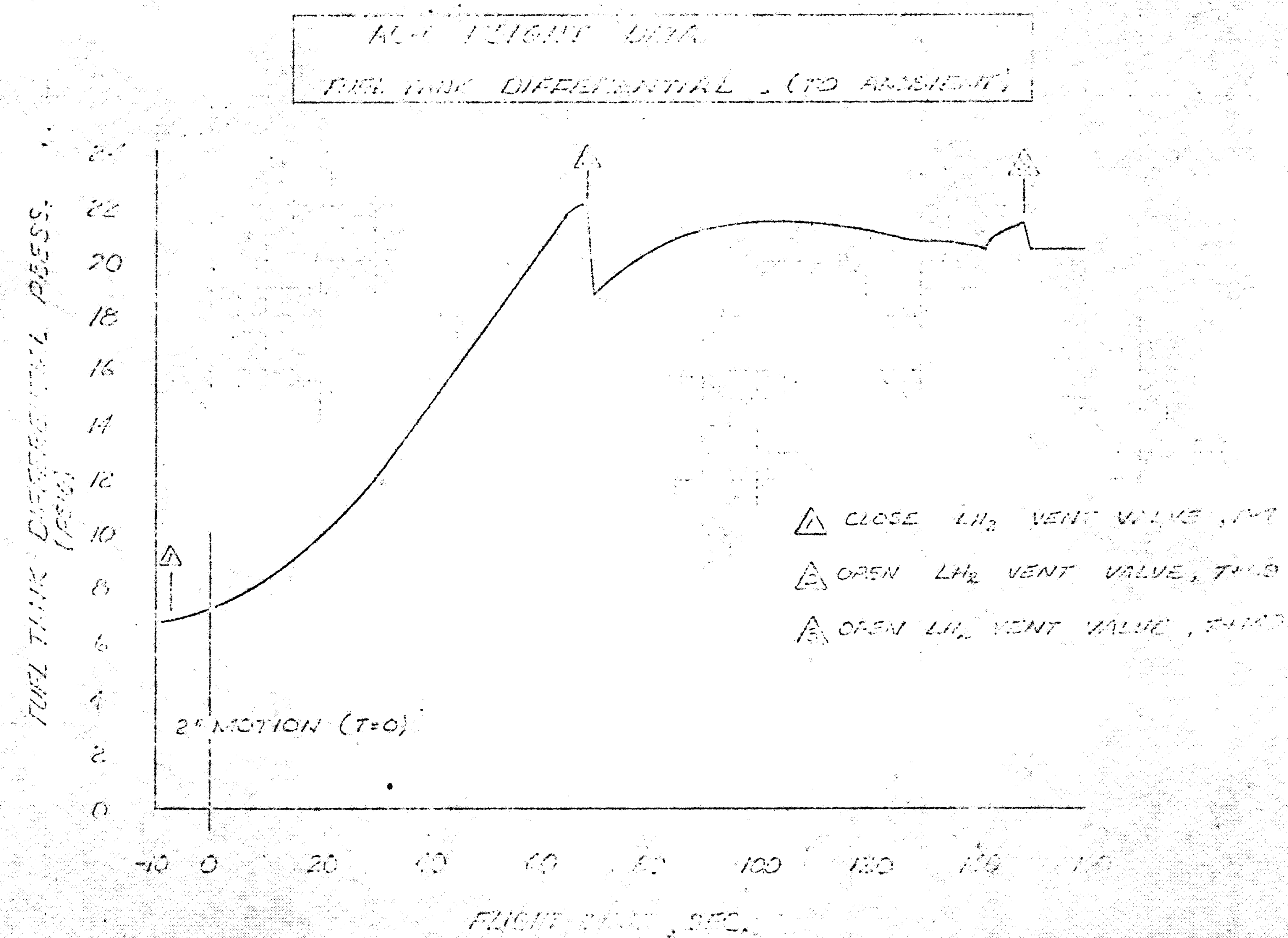


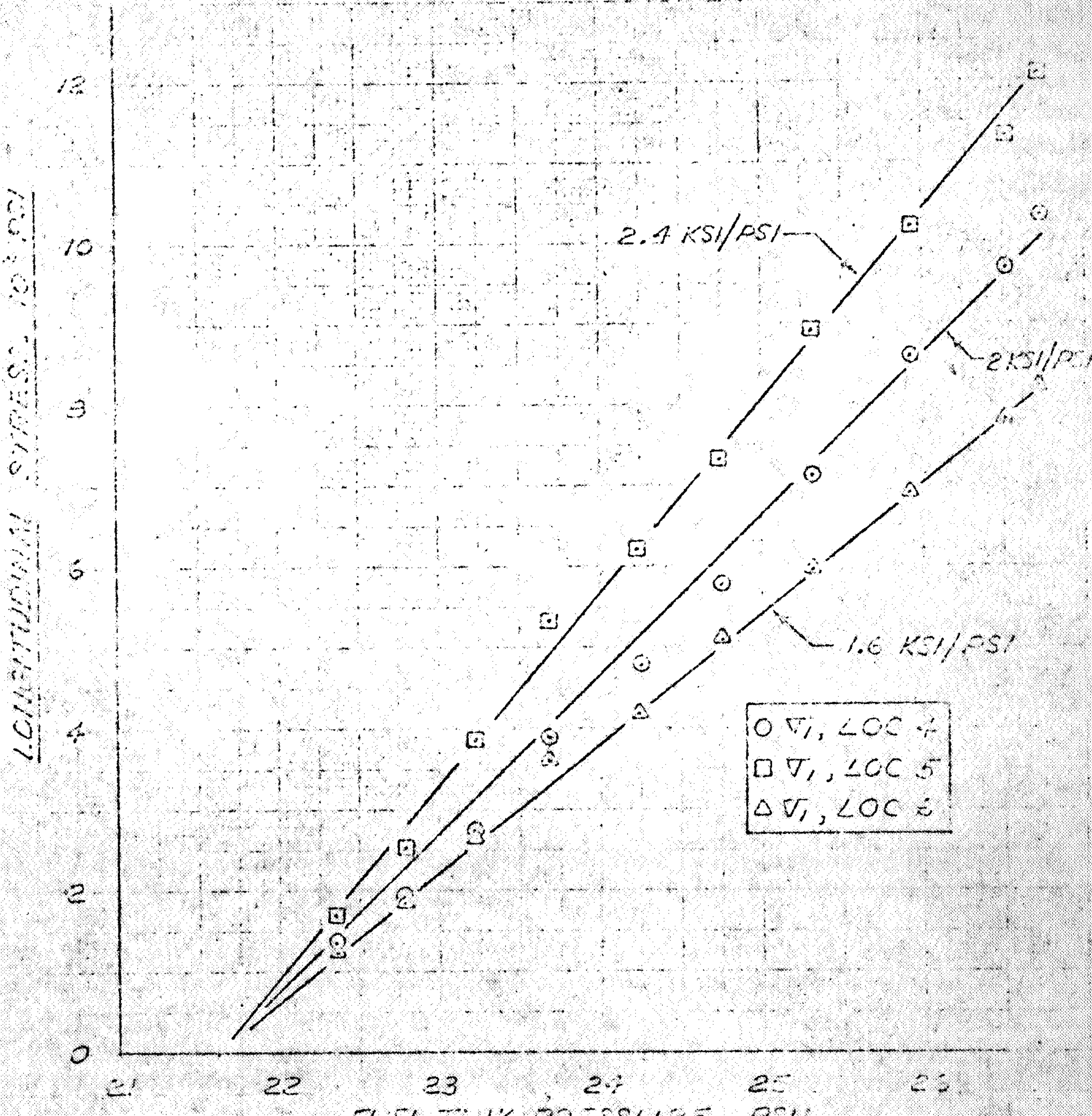
FIG. 2.


AC-6 FLIGHT DATA
FUEL TANK AND AMBIENT PRESSURE
FUEL TANK ULLAGE
ATMOSPHERIC



DIFFERENTIAL
(PSIG)
2" MOTION (T=0)
CLOSE LH2 VENT VALVE
OPEN LH2 VENT VALVE
0
2
4
6
8
10
12
14
16
18
20
22
-10
0
20
100

VARIATION IN PRESSURE-SKIN STRESS RELATIONSHIP, QUAD TANKING



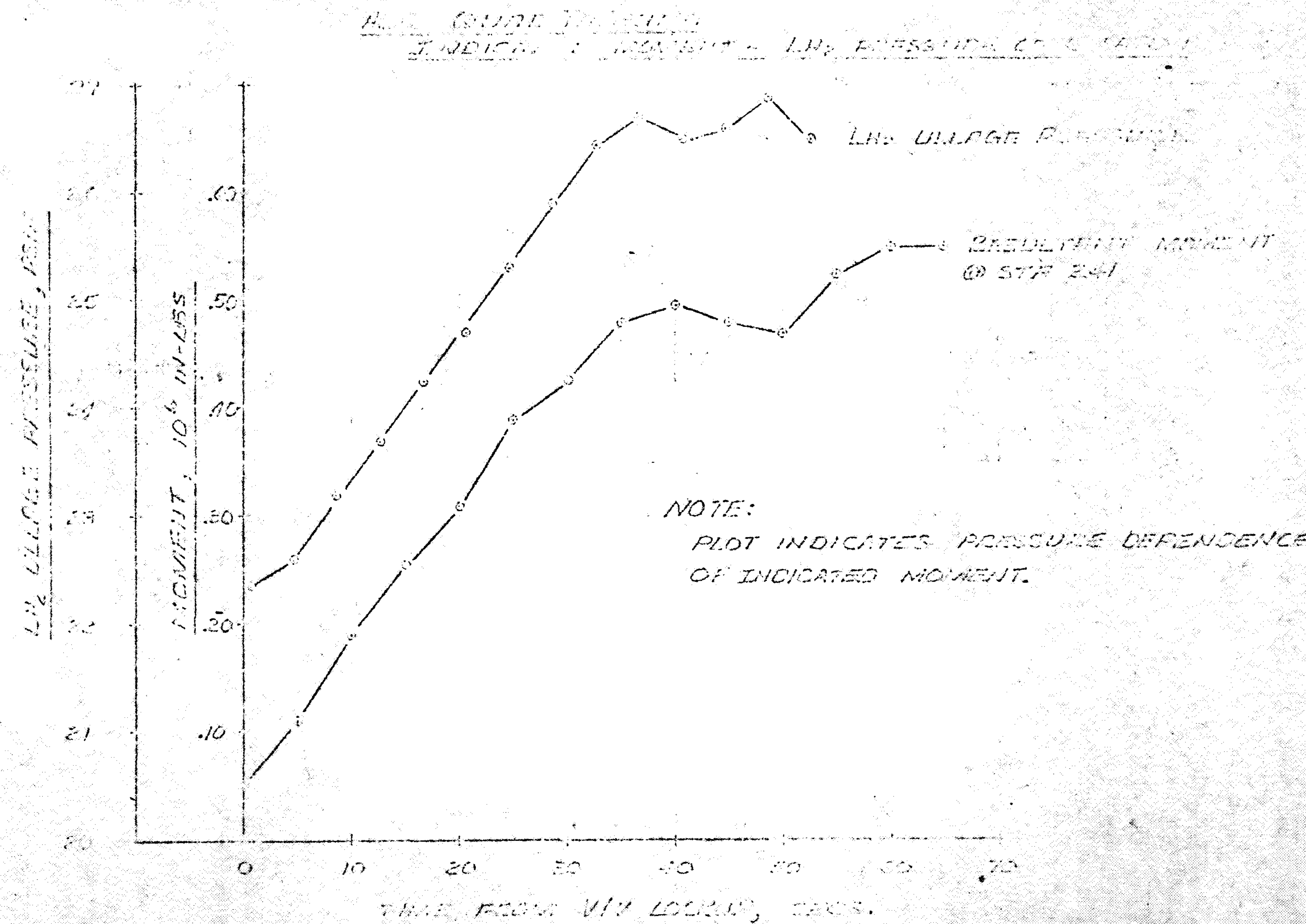
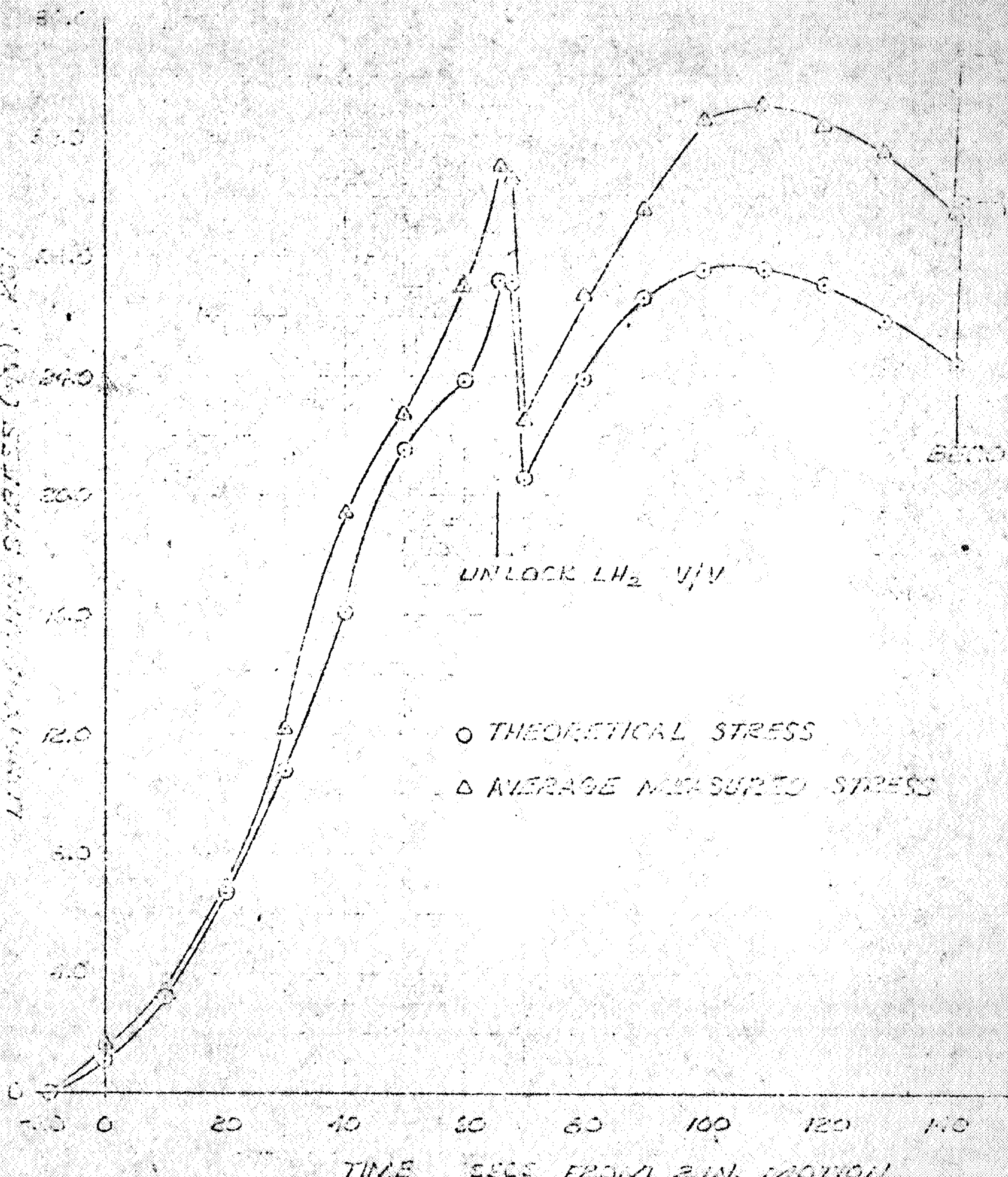

NOTE:
PLOT INDICATES PRESSURE DEPENDENCE
OF INDICATED MOMENT.
MOMENT, 10⁶ IN-LBS
.10
.20
.30
.40
.50
.60
21
0
10
20
30
40
70

FIG. 5.



UNLOCK LH2 V/V
BECO
○ THEORETICAL STRESS
△ AVERAGE STRESS
0
12.0
20.0
24.0
0
20
40
60
80
100
120
TIME

DEFLECTION VS. MEASURED STRAIN
NASA BEAM FIXTURE GAGE TYPE FNB-50-12E
LOT NO. 6A-7N GAGE FACTOR 2.26 ± 2%

DEFLECTION INCHES	AMBIENT TEMP.						-320°F						-423°F					
	STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.			STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.			STRAIN GAGE NO. 9 MICRO IN./IN.			STRAIN GAGE NO. 10 MICRO IN./IN.		
	RUN 1	RUN 2	AVG.	RUN 1	RUN 2	AVG.	RUN 3	RUN 4	AVG.	RUN 3	RUN 4	AVG.	RUN 5	RUN 6	AVG.	RUN 5	RUN 6	AVG.
0.0000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0.1247	510	509	510	-515	-500	-508	552	550	551	-563	-550	-557	560	550	555	-560	-550	-555
0.2438	978	988	983	-1000	-990	-995	1072	1050	1061	-1088	-1070	-1079	1060	1015	1038	-1075	-1065	-1070
0.3490	1395	1406	1401	-1420	-1408	-1414	1510	1490	1500	-1520	-1508	-1514	1510	1495	1503	-1510	-1500	-1505
0.4984	1908	1965	1937	-1915	-1988	-1947	2132	2100	2116	-2110	-2115	-2113	2145	2120	2133	-2125	-2120	-2123
0.3484	1278	1330	1304	-1260	-1320	-1290	1465	1425	1445	-1428	-1430	-1429	1460	1440	1450	-1450	-1450	-1450
0.2422	860	910	885	-832	-888	-860	1020	972	996	-970	-970	-970	1010	990	1000	-1000	-1000	-1000
0.1215	432	435	434	-377	-418	-398	490	458	474	-450	-450	-450	485	480	483	-470	-475	-473
0.0006	-78	-40	-59	112	60	86	-40	-70	-55	90	80	+85	-70	-70	-70	90	70	80
-0.1226	-575	-530	-553	610	550	580	-550	-595	-573	610	610	610	-580	-605	-593	600	610	605
-0.2415	-1028	-992	-1010	1060	1020	1040	-1075	-1100	-1088	1138	1125	1132	-1100	-1120	-1110	1120	1120	1120
-0.3441	-1400	-1380	-1390	1451	1410	1432	-1510	-1540	-1525	1575	1570	1573	-1520	-1560	-1540	1540	1560	1550
-0.4902	-1870	-1862	-1866	1980	1911	1996	-2120	-2140	-2130	2130	2170	2175	-2150	-2175	-2163	2190	2190	2190
-0.3421	-1235	-1225	-1230	1340	1270	1305	-1470	-1480	-1475	1520	1500	1510	-1480	-1500	-1490	1500	1505	1503
-0.2376	-800	-800	-800	920	840	880	-1013	-1030	-1022	1065	1050	1058	-1030	-1060	-1045	1040	1055	1048
-0.1172	-348	-330	-339	460	375	418	-490	-508	-499	540	520	530	-510	-540	-525	530	540	535
-0.0000	+132	+150	+141	-40	-120	-80	30	10	20	10	000	5	+20	000	+10	0	5	3

NOTE:
1. SR-4 GAGE FACTOR SETTING 2.00 ALL ABOVE READINGS RECORDED WITH THIS G.F.
2. BOTH GAGES MOUNTED IN LONGITUDINAL DIRECTION ON BEAM.

GENERAL DYNAMICS

Convair Division